An Age-Structured Model of Northern Rockfish, *Sebastes polyspinis,* Recruitment and Biomass in the Gulf of Alaska

October 30, 1999

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Executive Summary

The purpose of this report was to summarize the data available for an age-structured model of northern rockfish in the Gulf of Alaska (GOA), and to assess the fit of preliminary population estimates from the model to the data. Population estimates were obtained with AD Model Builder software and model formulation generally followed that described for GOA Pacific ocean perch (POP) stock synthesis model except where noted. The GOA POP AD model was used as a template for the GOA northern rockfish AD model and only changed where necessary to adapt it to the different demands of the northern rockfish data.

The model was fit to available GOA fishery catch and size composition data as well as triennial trawl survey size and age compositions. Triennial trawl survey biomass estimates were incorporated as an auxiliary index of abundance in order to scale the population estimates. A Beverton Holt spawner recruit model added additional structure to the model, and the number of parameters was reduced by fixing natural mortality at an independently estimated value and assuming a single selectivity for the fishery and the survey. Parameter estimation was improved by incorporating prior values and distributions for recruitment variability, survey catchability and steepness. Recruitment variability each year and selectivity at age were also constrained from within the overall model likelihood function, and ageing errors were incorporated into age-error and age-length transition matrices.

The model fit the age composition and biomass index poorly and did not satisfactorily describe the population structure. An examination of several alternative model likelihood weightings revealed that the most likely cause of the poor fit was an apparent inconsistency in the data between the age and length compositions. In particular, the length compositions were composed of a single mode that progressed in size through time. The model interpreted this mode as a single very large year-class, 1976, which dominated the population dynamics of the model. Alternatively, the age composition was composed of several less clearly defined modes that progressed in age through time. An alternative case was obtained by forcing the model to fit the age composition data. In this case, the model estimated several strong year-classes and the stock recruit relationship and selectivity curve appeared to be more reasonably defined.

Catch quotas of GOA northern rockfish have relied almost entirely on biomass estimates provided by NMFS GOA triennial trawl surveys. An age-structured analysis of northern rockfish population dynamics has been suggested as a way to improve the stock assessment. On the one hand, this age-structured model's fit to the data appears to be driven largely by the length compositions and indicates that there may not be a sufficient time series of age data to represent the population's age structure. On the other hand, the survey age data consistently shows multiple strong year-classes. New data has been added to this model since it was first introduced in the September 1999 preliminary SAFE report. The new survey age composition for 1996 and the new survey length composition for 1999 are consistent with previous age and length data, but the 1999 biomass estimate came in quite high. The consistent trends in new age compositions with the previous survey age data provide a good rationale for increasing the weight to age data in future modeling. Subjectively increasing the weight to the age data likelihood component supports a population representation close to that of the alternative case.

At this stage of development, the value of the model has been in its ability to incorporate several disparate fisheries and survey data sources. The model provided a subjective framework for evaluating the effect of varied likelihood component weightings, and suggested a rational for determining an appropriate level of confidence in apparently inconsistent data components. By incorporating more than one source of fishery data, the model could also be useful for moderating the effect of large fluctuations in the survey biomass data, such as the high 1999 estimate. However, estimates of selectivity and recruitment variability from this version of the model are poorly defined. $F_{40\%}$ and $F_{30\%}$ computations rely on the selectivity estimated from the model and these estimates are likely to change before the model is finalized. Consequently, this northern rockfish AD model was not used for the current stock assessment.

Introduction

The northern rockfish, *Sebastes polyspinis,* is one of the most abundant and commercially valuable members of its genus in Alaska waters. As implied by its common name, this fish has one of the most northerly distributions among the 60+ species of *Sebastes* in the north Pacific. Bottom trawl surveys of the Gulf of Alaska and Aleutian Islands indicate that northern rockfish is the second most abundant rockfish species in these regions, surpassed only by Pacific ocean perch, *S. alutus*. Since 1990, northern rockfish has supported a valuable domestic trawl fishery in Alaska. For the Gulf of Alaska region alone, recent catch levels have been around 5,000 metric tons (mt). Gross wholesale value of this fishery was estimated at $4 million in 1995.

The stock assessment of northern rockfish used to recommend catch quotas has relied almost entirely on biomass estimates provided by NMFS trawl surveys. The recent *Rockfish Stock Assessment Review* conducted by an outside review team expressed concern about the reliability of survey biomass and the use of average survey biomass as the estimate of exploitable biomass for many of the rockfish stocks. The review team specifically recommended attempting an age-structured analysis of northern rockfish to improve the quality of the stock assessment. Age and length composition data is available from the surveys and length composition data are available from the fishery. Collection of age composition data from the fishery was begun in 1998.

The purpose of this report was to summarize the data available for an age-structured northern rockfish stock assessment in the Gulf of Alaska (GOA), and to assess the fit of preliminary population estimates to the data. Population estimates were obtained with an age-structured model developed with AD Model Builder software (Otter Research Ltd.). Model formulation followed that described for Pacific ocean perch (POP) in the Gulf of Alaska (Heifetz and Ianelli 1992). Since 1992, Heifetz and Ianelli (Pers. Com. 1999) have reproduced their Gulf of Alaska POP model using AD Model Builder software. The formulation of the Gulf of Alaska POP AD model, hereafter referred to as the GOA-POP AD model was followed as closely as possible during construction of the Gulf of Alaska northern rockfish AD model presented below. Age-structured models have been described in detail elsewhere (Deriso et al. 1985; Doubleday 1976; Fournier and Archibald 1982; Methot 1989, 1991). This report attempts only to highlight changes made from the GOA POP stock synthesis model (Heifetz and Ianelli 1992) and issues unique to modeling the age structure of Gulf of Alaska northern rockfish.

Materials and Methods

Time series data

Foreign removals of slope rockfish from the Gulf of Alaska began as early as 1960 but the proportion of northern rockfish in the catch is not available. This assessment relied upon commercial catch data obtained after implementation of National Marine Fisheries Service (NMFS) management in 1977 and upon data from NMFS triennial surveys that began in 1984 (Clausen and Heifetz 1999; Tables 1 and 2).

Catch history

The total commercial catch (mt) of northern rockfish in the Gulf of Alaska during 1977-1999 was summarized by combining the foreign, joint venture, and domestic fisheries (Table 3, Figure 1). Domestic catches were not available prior to 1990. Domestic catches from 1984 to 1989 were estimated by the ratio of domestic northern rockfish to domestic slope rockfish reported by the 1990 NMFS observer program (Table 6.2 Heifetz et al. 1997, Table 1 Clausen and Heifetz 1999):

$$\text{Northern rockfish catch}_i = \frac{\text{northern rockfish catch}_{1990}}{\text{slope rockfish assemblage catch}_{1990}} * \text{slope rockfish assemblage catch}_i$$

where i = {1984, 1985, …, 1989}

Domestic catches in 1997 and 1998 were provided by Heifetz et al. (1998). Error in the predicted catch was allowed including a weighting factor (λ_1) in the likelihood due to total catch biomass, but the effect on estimated catch caused by varying this weight in the likelihood has not yet been examined (Appendix A).

Fishery size composition

Annual estimates of length composition from the commercial fishery were available from the NMFS observer program for the years 1990-1998 (Table 4, Figure 7). Proportions at length were calculated for 24 ten-millimeter length bins (≤ 150 - 380+). The plus length bin was chosen to approximate the current estimate of L_inf, 383 (mm), from the von Bertalanffy (LVB) relationship (Table 8, Figure 3). These proportions at length were assumed to represent a random sample of the fishery. The number of fishing hauls with length data was used in the model likelihood as a measure of the confidence in the size composition data (Table 4, Appendix A).

Survey size composition

Population length composition estimates were available from the NMFS GOA triennial trawl surveys for the years 1984 - 1999 (Table 5, Figure 8). Survey proportions at length were grouped into the same length bins used for the fishery data and the number of survey hauls with length data was used as a measure of the confidence in the size composition data (Table 13, Appendix A).

Proportions at length from the survey and fishery were plotted together for the years with overlapping data (Figure 2). There was no consistent bias between the fishery and survey proportions. Consequently, a single selectivity was assumed in the northern rockfish model for both the survey and the fishery (Appendix A). There was a progression in the length frequency of the survey population over time that was not reflected as strongly in the fishery size composition. It is not clear how this progression affects the assumption of a single selectivity.

Survey age composition

Population age composition estimates were available from the NMFS GOA triennial surveys for the years 1984, 1987, 1990, 1993, and 1996 (Table 6, Figure 9). The 1984 northern rockfish ages were obtained from a limited number of hauls but were included in the assessment because the trends in age compositions matched those found in later surveys (Figure 9). Proportions at age were grouped into 21 age bins (2 - 23+). The plus age bin, 23+, was chosen to approximate the age at which length begins to reach the asymptote from the LVB relationship (Figure 3). The number of survey hauls with age data was used as a measure of the confidence in the age composition data (Table 13, Appendix A).

Survey biomass index

Population biomass estimates were available from the GOA triennial surveys for the years 1984 - 1996 (Table 7, Figure 6). Standard error (se) and coefficient of variation (CV) were also available (Table 7). The standard error estimates were used as a measure of the confidence in the biomass index (Appendix A).

The population biomass, size composition, and age composition estimates were recompiled from the RACE survey database (RACEBASE) for this report (Pers. Comm. Michael Martin, NMFS RACE Division). Fishing power correction (fpc, e.g., Heifetz et. al. 1994) estimates were not incorporated into the current survey estimates. Fpc's for GOA northern rockfish were 1.0 and 1.03 in 1984 and 1987 respectively, which were probably below the resolution available from the data (Pers. Comm. Michael Martin, NMFS RACE Division). Consequently, population estimates may differ slightly from those previously reported (e.g., Heifetz et. al. 1997).

Data Aggregated over Time

Parameters estimated independently

Several biological parameters were estimated independently of this assessment (Table 8). The proportion of females mature at age, m(a) was modeled using a form of the logistic equation and the results are tabulated in Table 9:

$$m(a) = \frac{1}{\left(1 + \exp\left(\frac{-(a + a_{0.5})}{s_p}\right)\right)}$$

The parameter $a_{0.5}$ is the female age at 50 % maturity, and σ_p is the instantaneous rate of fish maturation (Heifetz et al. 1998; σ_p obtained from Chris Lunsford NMFS Auke Bay Laboratory, 1999).

Length at age was re-estimated for this assessment using an additive error structure. Length at age was modeled with the LVB growth function (Table 8, Figure 3):

$$L = L_\infty * \left(e^{(-k(t-t_0))}\right)$$

Sexual dimorphism in growth was not examined at this stage of model development, although it has been found in other rockfish species in Southeastern Alaska (e.g., Quinn and Deriso 1999; p. 174).

Weight at age

Weight at age was modeled for northern rockfish in the Gulf of Alaska from raw NMFS GOA triennial trawl survey data gathered during the years 1984 - 1993. Schnute (1981) developed a general 4 parameter growth model that contained several commonly used weight at age models as special cases of the full model. Schnute (1981) also provided a statistical F-test to choose a best model from among the different cases. Weight at age data for northern rockfish was pooled across sexes and over the survey years 1984 - 1993 and used to estimate the best Schnute weight at age model. Five cases of the Schnute model were examined. Cases 1 - 4 corresponding to those described in Schnute (1981) and case 5 was obtained by setting $\gamma = 1$ (equivalent to the LVB growth function). Examination of the residuals showed an increasing error with age; consequently, a multiplicative error structure was assumed. Multiplicative case 2 was chosen as the best model based upon F-tests for models with different numbers of parameters and upon lowest RSS for models with the same number of parameters. The case 2 multiplicative growth model (Schnute 1981) can be written:

$$\ln(W(t)) = \ln(w_1) + \left[(\ln(w_2) - \ln(w_1)) * \frac{(1 - \exp(-k(t - t_1)))}{((1 - \exp(-k(t_2 - t_1))))}\right]$$

Parameter estimates are shown in table 10. Weight at age was used to calculate survey biomass and commercial catch biomass from the estimated numbers at age.

For the current model, weight at age data is cropped at age 23 (Table 11, Figure 4). Cropping the weight at age data was justified by comparing the weight at age model with a model obtained by re-estimating the parameters after pooling all ages greater than 23 into the 23 age bin. The resulting pooled age model did not appear visually different from the model estimated without pooling the ages past 23 (Figure 4). Similarly, other aggregated data models used in the assessment (i.e., length at age, maturity at age) were also cropped at the maximum age of the model (e.g., 23, for the 23+ age bin) rather than re-estimated.

Age-error transition matrix

An age error transition matrix was constructed from two independent readings of otoliths collected from NMFS GOA triennial trawl surveys during the years 1984 - 1993 (Table 12, Richards et al. 1992, Heifetz et al. 1998). Each element of the transition matrix provided the probability of assigning age j' when true age was j. The matrix did not consider bias (i.e., true age), so these probabilities should be considered minimum estimates of ageing error. The numbers of fish examined for age and the numbers of survey hauls with examined fish are tabulated in Table 13.

Age-length transition matrix

An age-length transition matrix was constructed from raw age-length data collected during the NMFS GOA triennial trawl surveys of 1984 - 1993 in a manner analogous to the age-error transition matrix. Each element of the table provided the probability of obtaining length k when true age was j. The mean size at age was assumed to follow the LVB growth function defined above with a normal error distribution for length at age. The standard deviation of length at age was modeled as a linearly increasing function of age (Figure 5).

LVB parameters can be correlated with other parameters of the catch at age model. Consequently, the LVB parameters were estimated independently of the AD model. In this sense, the length at age matrix used here differs from that described by Methot (1990) who estimated the LVB parameters from within the matrix, but did not incorporate ageing error.

It is interesting to note that ageing error could also be incorporated into the length at age transition matrix by first passing the age data through the ageing error transition matrix. In this way the true ages produced by the AD model could be transformed to an estimation of observed ages for use in the length at age matrix. The length at age matrix could then transform observed age to observed length, with either length at age proportions or a length at age model such as the LVB (e.g., see Sigler et. al., Alaska sablefish Assessment for 2000).

Model structure

Except for the steepness, h, and recruitment variability, σ_R, parameters discussed below, the log parameters were estimated rather than parameters on the original scale for reliability in the estimation process (Kimura 1989, 1990). Auxiliary information was added to the model in the form of independent survey biomass estimates. Survey biomass (B) was used as an index (I) of abundance by estimating the parameter (Q^s):

$I = Q^s * B$

In this sense, the parameter Q^s can be interpreted as the efficiency of the survey sampling gear. In the current model formulation, Q^s was allowed to vary from one.

Additional structure was added to the model by incorporating a stock recruit relationship (Heifetz and Ianelli GOA POP AD model 1999). The population was assumed to be at equilibrium prior to the beginning of the available data for the fishery in 1977 and a Beverton Holt spawner recruit model was used. The relationship was re-parameterized so that the stock recruitment parameters would have biological interpretations (e.g., p. 88 Hilborn and Walters 1992). The number of age 2 recruits for the years i {1977, 1978, …, 1999} (22 year-classes) can then be described by:

$$R_i = \frac{S_{i-2} e^{r_i}}{a + bS_{i-2}}$$

Where

R_i = recruitment at age 2 in year i

S_i = biomass of female spawners in year i

r_i = recruitment anomaly for year i

a, b = stock - recruitment function parameters

$$a = \frac{B_0}{R_0}\left(1 - \frac{h-2}{0.8*h}\right)$$

$$b = \frac{5h-1}{4hR_0}$$

B_0 and R_0 are equilibrium biomass and recruitment, respectively. The parameter "h" can be interpreted as the "steepness" of the stock-recruit relationship, or the speed at which the spawner-recruit curve reaches the maximum or asymptote. An additional parameter, σ_R, representing recruitment variability was estimated from within the overall likelihood function (L_6 - Appendix A).

Selectivity was constrained from within the model likelihood function (Heifetz and Ianelli GOA POP AD model 1999). Selectivity was allowed to vary as a smooth function of age up to the first fully selected age (L_7 - Appendix A). The number of partially selected ages (n_selages) was set to the number of ages (n_ages) in the model (i.e., 22). In this way, the model estimated a maximum selected age. A second penalty function limited the degree of the dome shape if it occurred (L_8 - Appendix A).

Parameter estimation was improved by incorporating prior distributions for initial values of recruitment variability, $\sigma_{R,}$ survey catchability, Q^s, and steepness, h. (Heifetz and Ianelli GOA POP AD model 1999; Table 8, Appendix A.). It was assumed that the initial values and their prior distributions were similar for northern rockfish and Pacific ocean perch in the Gulf of Alaska. Consequently, prior estimates and their distributions were taken directly from the GOA POP AD model (Heifetz and Ianelli Pers. Comm. 1999).

For the current model formulation, natural mortality, M, was fixed at an independently estimated value, 0.06 (Table 8).

Results

Data fit

The model fit the trawl survey abundance data poorly (Figure 6). The model was also unable to represent the sharp jumps in the trawl survey abundance indices between 1984 and 1987 and again between 1996 and 1999. The fit was better for both the fishery and the trawl survey size composition, but the fit of the trawl survey age composition was also poor (Figures 7, 8 and 9). This age data implied an above average 1976 year-class. This year-class was overestimated by the model. This age data also implied above average 1970 and 1982/1984 year-classes; but these year-classes were underestimated by the model. However, with the addition of the 1996 survey age composition data, the model began to represent the strong year-class of 1970 (Figures 9 and 13). The trawl survey abundance and age data are inconsistent. The age data support some increase in abundance during the late 80's, but support neither the sharp jump of the abundance index in 1987 nor the jump in 1999.

Population representation

The model implies that northern rockfish abundance more than doubled during the period from 1977 to 1998, peaking in the late 1980's, then decreasing during the 1990's (Figures 6 and 9). The increase was due to an exceptionally strong 1976 year-class, almost four times stronger than any other estimated year-class.

The model had trouble defining a reasonable selectivity curve. In the current formulation, the selectivity curve implies that selectivity is relatively low until about age 12 and that maximum availability isn't reached until age 22 (Figure 6).

The model also had difficulty estimating catchability (Q^s), steepness (h) and recruitment variability (σ_R). In the current formulation, the parameter estimate for steepness tended to its upper bound (1.0). However, the addition of prior distributions and the reduction in parameters by assuming a single selectivity allowed the model to obtain an estimate of Q^s (0.4) and σ_R (0.7) and associated standard errors of 0.1 and 0.2 respectively.

Starting parameter values were varied to determine whether they dictated the solution. The parameters R_0, equilibrium recruitment, and Average F, average fishing mortality, determine the scale of model biomass estimates. Starting values for these parameters were taken from the GOA POP AD model. Twice and half the original starting values produced parameter estimates nearly identical to the original ones.

Effect of likelihood weighting

We tested the model sensitivity to the likelihood weights on the survey age data and the abundance index (Figure 10, Appendix A). Increasing the likelihood weight on the age data improved the fit of the age data, but worsened the fit of the other data. Increasing the likelihood weight on the abundance index improved the fit of the abundance index and all the other data except the age data. These results imply that there is some contradiction between the age data and the other data, and that the most likely population representation implied by the age data differs from that implied by the other data. The purpose of the next section is to explore this difference and why it might occur.

Comparison of base with an alternate case

The model described so far does a poor job of representing the observed age data. An alternate case was constructed which forced the model to represent the observed age data exactly. The base and alternate cases are the same except that in the alternate case, the value of the weighting term (λ_3) applied to the age data was increased from 1 to 50, (in order to fit the age composition exactly), and the value of the weighting term (λ_7) applied to the selectivity regularity was increased from 10 to 100 (in order to smooth the fluctuating selectivity curve which resulted from increasing λ_3; Figures 9 and 10; Appendix A).

The base case and alternate case imply similar 1999 female spawning biomass of about 50,000 mt (Figures 6 and 12). With the addition of the 1996 survey age compositions they also imply similar trends in survey biomass. Estimated survey biomass increased then decreased for both the base and alternate cases. Inconsistencies in estimated selectivities and annual recruitments remain the major differences between the base and alternate cases. A single very strong year-class is estimated for the base case and this year-class gradually becomes available to the survey, reaching maximum availability at about age 22. The increase in estimated survey biomass in the base case is based on the increasing availability of the single very strong 1976 year-class. Instead of one very strong year-class, multiple strong year-classes are estimated for the alternate case. Also, selectivity reaches a plateau at about age 11 rather than continuing to increase as in the base case.

Different recruitment patterns are estimated for the base and alternate cases because the alternate case matches the observed age data, but the base case does not. Abundance and recruitment are estimated from four main data sources: an abundance index (trawl survey), survey length data, survey age data, and fishery length data. The index data implies that abundance initially increased, then subsequently decreased, then sharply increased again. The age and length data may imply different recruitment scenarios for this abundance increase of 1987 and do not imply an abundance increase in 1999. The size data may imply that the abundance increase in 1987 is due to one very large year-class (base case; Figures 7 and 8), while the age data may imply that the abundance increase is due to multiple large year-classes (alternate case; Figures 9 and 11). The size data generally is unimodal, whereas the age data usually is multi-modal. Although the size data is intended to help estimate recruitment strengths, size data is a messy predictor of age and therefore year-class strength. Whether there are multiple or single year-classes is difficult to differentiate with the size data. In contrast, the age data for northern rockfish appears to be a good predictor of year-class strength. For example, the mode at 8 years in 1984 is followed by modes at 11 years in 1987 and 14-15 years in 1990, implying a strong 1976 year-class (Figures 9). This distinction also can be seen in the fit to the age data when the base and alternate cases are compared (Figures 9 and 11; 6 and 12 respectively). The predicted age compositions for the base case show one very large year-class, but the fit to the age data is poor, implying that the recruitment estimates are not based on the age data. In contrast for the alternate case, there are three large year-classes and the fit to the age data is good.

Examination of the likelihood values indicate that a likelihood weight greater than three, but less than 10 would be sufficient to improve the models fit to the age data (Figure 10). A weight less than 10 would improve model fit to the age data while not dramatically reducing the fit to the other contradictory data components (e.g., survey size composition; Figure 10). The survey age data consistently shows multiple strong year-classes (Figures 9 and 11). Trends in 1996 age data are consistent with the previous survey age data and provide a good rationale for increasing the weight to age data in future modeling.

Additional data

New data has been added to the GOA northern rockfish AD Model since the NPFMC October 1999 Plan Team Meeting. This data includes the 1999 GOA survey biomass and survey size estimates, the 1996 GOA survey age compositions, and the 1999 GOA fishery catch numbers. With the addition of new data, the trend in biomass estimates for the base case has changed from a consistent increase to an increase followed by a decrease (Figure 13). This now matches the trend in biomass estimated by the alternative case, which has remained unchanged, increasing in the late 80's then decreasing to 1999 (Figure 12). Estimated survey biomass decreased by 1999 in the alternate case because the last strong year-class, 1984, reached the availability plateau by 1993 and was followed by weaker year-classes. With the addition of new data, the base case better represents the observed age composition, which results in a decreased estimated biomass by 1999. With the addition of new data, the base case also begins to represent the strong year-class of 1970, which is reflected in a higher recruitment estimate for that year-class (Figure 13). The 1999 length composition data continues the trend of increasing length found in the previous survey length compositions (Figure 8)

The 1999 GOA survey biomass estimate for northern rockfish was exceptionally high (Table 7). The age-structured model relies on observed biomass estimates to obtain an appropriate scale for the population biomass but does not fit the biomass estimates well. In addition, the model uses standard error to weight the fit to biomass. The large 1999 biomass resulted primarily from one large (~8 mt) haul (Figure 14). The overall trend in the GOA northern rockfish survey CPUE for 1999 was down from previous survey years (except for 1984; Figure 14). The difference between the overall low 1999 survey catch levels and the one large haul resulted in a very large1999 biomass standard error (Table 7, Figure 13). Consequently the model did not place much emphasis on the 1999 survey biomass.

Response to NPFMC September GOA Plan Team and October SSC Suggestions

In September, the GOA Plan Team suggested smoothing the selectivities in the alternate case model. In response, the weight (λ_7) to the selectivity regularity likelihood was increased in the alternate case from 10 to 100, which resulted in a smoother selectivity curve (Figure 12, Appendix A). Also in this regard, the Plan Team suggested the re-assessment of natural mortality for GOA northern rockfish. Given the availability of new survey age and length data it seems worthwhile to update the estimate of M, but this has not yet been accomplished.

In comments that did not make it into the Plan Team minutes, the team also suggested an examination of the disaggregated 1984 CPUE data in comparison with other survey years. CPUE plots for survey years 1987 – 1999 show large catches of GOA northern rockfish in nearly the same locations fished in 1984 with low catches. Areas not fished in 1984 (primarily the Eastern Gulf) did not have large catches of northern rockfish in other survey years. In all years except 1984 large catches occur in approximately the same locations along the fringes of areas sampled by the survey. It is possible that for some reason the 1984 survey was less effective along the boundary of the survey area, but it is impossible to tell from the CPUE plots alone. The CPUE plots also show that the high 1999 biomass estimate and associated standard error resulted from a single relatively large haul in a trend of otherwise low catches.

Neither the length compositions nor the age compositions of GOA northern rockfish show signs of a large year-class recruiting to the population in recent years (Figures 8 and 9). Consequently, the model estimate of biomass actually decreased in 1999 in spite of the large 1999 survey biomass estimate. In this regard the Plan Team suggested that it might be worthwhile to examine the length compositions by haul for smaller length bins. This would reveal whether or not small length bins are well represented in the length data or if they are only coming from a few hauls. An initial examination of the survey length data by haul revealed that the smaller length classes are well represented by a large number of hauls, and a detailed examination of the length composition by haul was not conducted.

In October, the NPFMC SSC suggested that the stock assessment scientists might want to consider using this model for the current 2000 stock assessment. Their reasoning was that the 1999 biomass estimate of northern rockfish came in quite high, and that the current stock assessment may also be high. Using the new stock assessment model would use all of the best available fisheries information and might moderate the 1999 biomass estimate. The SSC also suggested using the alternative case of the model because northern rockfish are thought to be easy to age, and the year-class strengths from the alternative approach appear more realistic. However, estimates of selectivity and recruitment variability from both the base and alternate cases of this model are poorly defined. Selectivity is constrained from within the likelihood function rather than being given a functional form. This may affect the selectivity curve's sensitivity to changes in the model likelihood weightings, such as those used for the base and alternate cases. Selectivity estimates are instrumental for computing F_{ABC} and F_{OFL} and selectivity estimates are likely to change before the model is finalized. Consequently, this northern rockfish AD model was not used for the current stock assessment.

Conclusions

Given the limited age data and the qualifications discussed above, the results appear to be within reason. There are "too many" recruits of one age class in the base case, and the selectivity is unusual for its slow build up to maximum selectivity. These features may be due to having only 5 years of age compositions to estimate selectivity and recruitment. The age compositions themselves, especially of the younger age-classes, are not being fit. This may result from the lack of agreement between trends in the survey age composition when compared to trends in the fishery and survey length compositions. There are several years of length data available, but length is not always a good predictor of recruitment strength and age selectivity. The 1996 survey age data was a helpful addition to the model. The year-classes present in the 1996 age composition matched those of earlier years and provide a rational for weighting the age compositions more heavily as in the alternate case.

Acknowledgments

The authors would like to thank James N. Ianelli, NMFS REFM Seattle, for his help with the initial stages of model development, for a report obtained off of the NMFS Alaska regional web pages (Ianelli and Zimmerman 1998) that was used as an outline for this document, and for compiling the northern rockfish CPUE plots presented here. Michael Martin, NMFS RACE Seattle, recompiled the northern rockfish Gulf of Alaska triennial survey biomass index, size composition, and age composition estimates used for this report, and provided valuable help with interpreting the survey data.

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Tables

Table 1. Fishery and regulatory actions that may have influenced the commercial catch or management of northern rockfish in the Gulf of Alaska.

Date	Fishery and Regulatory Actions (Clausen and Heifetz, In Prep)
1960	Directed foreign fishery for rockfish began in Alaskan waters by Soviet and Japanese bottom trawlers.
1976	Passage of the Magnuson Fisheries Conservation and Management Act set in place regulatory policies that allowed for the development of a joint venture fishery which eventually resulted in the domestic fishery replacing the foreign fleet.
1977	Estimates of numbers of northern rockfish captured in the foreign and joint venture commercial fishery operating in the Gulf of Alaska available for the first time from the NMFS foreign and joint venture observer program.
1979	Northern rockfish placed in the Pacific Ocean Perch Assemblage by the NPFMC and fishing regulated under a single quota for the entire assemblage.
1984	Beginning of a completely domestic fishery for rockfish in which U.S. vessels both caught and processed the fish.
1988	Northern rockfish placed in the Slope Rockfish Assemblage by the NPFMC and fishing regulated under a single quota for the entire assemblage.
1990	Estimates of numbers of northern rockfish captured in the domestic commercial fishery operating in the Gulf of Alaska available for the first time from the NMFS domestic observer program.
1991	Northern rockfish placed in the "Other Rockfish" group by the NPFMC and fishing regulated under a single quota for the entire group.
1993	Northern rockfish placed in its own management group by the NPFMC and fishing regulated under a northern rockfish quota.

Stars indicate major transitions in the availability of fishery data.

Table 2. List of data and time periods covered for the current assessment.

Data	Years
Survey biomass (mt)[b]	1984[a], 1987, 1990, 1993, 1996, 1999[f]
Survey size composition [b, c]	1984, 1987, 1990, 1993, 1996, 1999
Survey age composition [b]	1984, 1987, 1990, 1993, 1996
Combined commercial catch (mt) from the foreign, joint venture, and domestic fisheries	1977 - 1999
Fishery catch size composition	1990 - 1998

Data aggregated over time	Years (sample size)
Weight at age model[d]	1984, 1987, 1990, 1993
Ageing error transition matrix [d, e]	1984, 1987, 1990, 1993
Age length transition matrix [d]	1984, 1987, 1990, 1993

[a] 1984 survey includes the Western and Central Gulf, 1987-1996 surveys include the Eastern, Central and Western Gulf. Additionally, the 1984, and to a lesser extent 1987, survey relied heavily upon Japanese survey vessels (~50% of effort, Pers. Comm. Michael Martin, NMFS, RACE 1999) which fished primarily the deeper stations and utilized different gear than the standard adopted by American vessels.
[b] Population estimates or numbers expanded out by population estimates, based upon random stratified GOA samples summed to get an area wide total by year or pooled over years.
[c] There is additional raw survey size data in the RACE database (RACEBASE) that was not used in this assessment for the years 1978,79,80,81,82,83,84,85,87,90.
[d] These estimates based upon raw survey data from (RACEBASE) ~9/98
[e] These estimates based upon two readings of the same fish, in some cases by the same reader.
[f] The large 1999 survey biomass estimate was influenced by a very large survey catch of ~8 mt.

Table 3. Commercial catch (mt) of northern rockfish in the Gulf of Alaska 1977-1999 by the foreign, joint venture, and domestic fisheries.

Year	Foreign	Joint venture	Domestic	Total
1977	622	0	0	622
1978	553	0	0	553
1979	666	3	0	669
1980	809	tr	0	809
1981	1,469	0	0	1,469
1982	3,914	0	0	3,914
1983	2,705	911	0	3,616
1984	489	492	10[a]	991
1985	tr	108	66[a]	174
1986	tr	11	237[a]	248
1987	0	51	391[a]	442
1988	0	tr	1,107[a]	1,107
1989	0	0	1,527[a]	1,527
1990	0	0	1,697	1,697
1991	0	0	4,528	4,528
1992	0	0	7,770	7,770
1993	0	0	4,825	4,825
1994	0	0	5,968	5,968
1995	0	0	5,634	5,634
1996	0	0	3,386	3,386
1997[b]	0	0	2,947	2,947
1998[b]	0	0	3,048	3,048
1999[c]	0	0	5,381	5,381

[a] Northern rockfish catches in 1984-1989 estimated from the ratio of northern rockfish to domestic slope rock fish reported in the slope rockfish assemblage by the 1990 NMFS observer program.
Sources: U.S. GOA commercial catch (mt) of slope rockfish assemblage (SRA) (Table 6.2 Heifetz et al. 1997)
GOA commercial catches (mt) of northern rockfish (NR) table 1 (Clausen and Heifetz, 1999).

[b] 1997 and 1998 catches provided by Heifetz et al. (1998)

[c] NMFS Alaska Region Home Page catch statistics (as of October 1999) http://www.fakr.noaa.gov

Table 4. Fishery numbers at length data for northern rockfish in the Gulf of Alaska 1990 - 1998; Proportions at length binned into a plus group at 380+ mm for the model.

	Number of fish sampled at length by year									
Length-class (mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	
150	0	0	0	0	0	1	0	0	0	
160	0	0	0	0	0	0	0	0	0	
170	0	0	0	0	0	0	0	0	0	
180	0	0	0	1	0	1	0	0	1	
190	0	0	0	0	0	0	0	0	1	
200	1	0	0	0	0	2	0	0	0	
210	0	2	0	0	0	1	0	0	2	
220	0	0	0	0	1	5	0	0	3	
230	2	1	0	0	0	8	0	0	3	
240	5	1	0	1	0	24	1	8	8	
250	8	9	1	4	0	47	2	34	2	
260	4	21	3	10	1	74	0	72	6	
270	18	33	4	11	5	97	3	106	5	
280	36	64	17	23	14	88	5	109	9	
290	73	110	38	57	29	110	9	109	14	
300	80	288	78	112	57	134	30	90	24	
310	96	529	173	248	135	164	26	57	23	
320	151	967	385	484	246	222	66	62	60	
330	207	1,733	670	830	568	453	162	108	109	
340	333	2,550	1,247	1,132	946	864	351	206	211	
350	547	2,741	1,912	1,631	1,421	1,364	706	426	475	
360	800	2,008	2,162	1,754	1,623	1,652	1,026	618	891	
370	738	1,222	2,128	1,359	1,391	1,714	1,041	681	1,160	
380	550	610	1,824	1,073	811	1,371	785	616	1,069	
390	360	288	1,286	729	431	863	544	371	771	
400	168	131	810	514	203	400	346	207	445	
410	79	87	443	359	96	211	191	95	207	
420	37	27	165	189	55	162	95	43	82	
430	18	47	59	49	38	117	48	19	46	
440	8	32	55	9	28	97	22	9	19	
450	2	33	49	3	25	85	22	2	4	
460	1	35	2	0	9	67	13	0	1	
470	2	11	4	0	3	46	16	0	1	
480	1	6	5	0	1	17	10	0	0	
490	1	1	3	0	1	5	6	0	0	
500	1	0	1	0	0	2	1	0	0	Totals
Number of fish	4,327	13,587	13,524	10,582	8,138	10,468	5,527	4,048	5,652	75,853
Number of hauls	41	135	112	93	90	114	89	59	84	817

Table 5. Survey numbers at length data for northern rockfish in the Gulf of Alaska 1984 - 1999; Proportions at length binned into a minus group, £150 mm, and a plus group, 380+ mm, for the model.

	Estimated population of fish at length by year (millions of fish)					
Length class (mm)	1984	1987	1990	1993	1996	1999
90	0	0	0	0	13,388	30,901
100	0	103,938	10,277	0	9,886	37,419
110	0	51,969	10,277	0	122,973	0
120	0	97,092	0	0	239,439	61,605
130	59,053	155,281	0	0	151,022	72,674
140	324,789	357,304	0	0	16,285	67,864
150	679,105	814,863	89,965	19,517	49,598	47,865
160	501,947	876,247	0	40,887	39,106	70,806
170	354,316	1,111,536	30,834	102,026	93,811	39,519
180	564,214	996,556	0	169,235	120,927	144,622
190	406,651	1,148,477	83,769	85,223	65,222	204,844
200	324,927	1,860,082	99,209	74,698	90,680	193,634
210	199,948	2,175,616	202,320	99,524	88,830	361,422
220	375,454	2,304,674	518,110	235,827	257,262	512,334
230	550,064	2,694,506	829,903	397,370	282,637	1,027,833
240	1,187,511	3,029,441	1,786,614	498,269	245,107	545,660
250	1,578,563	3,494,853	1,709,069	1,006,915	381,305	660,661
260	1,860,110	3,484,764	4,509,979	808,867	854,282	1,841,186
270	2,947,288	4,015,772	3,691,138	1,037,717	1,004,269	591,945
280	3,469,821	5,207,057	2,516,020	1,178,971	675,142	1,709,984
290	5,786,128	10,140,621	2,599,920	1,050,782	982,387	554,513
300	6,219,410	16,545,187	1,938,575	1,852,014	1,106,017	763,117
310	6,849,696	27,304,128	3,391,428	2,221,455	1,956,615	705,158
320	6,291,943	32,392,881	5,791,568	6,240,299	2,488,308	8,121,952
330	5,207,060	30,239,348	13,646,739	8,443,560	3,266,424	9,372,340
340	4,077,810	28,213,782	19,058,443	13,922,930	4,178,094	10,699,211
350	3,511,733	20,081,229	21,077,802	22,529,371	7,275,690	16,324,239
360	4,102,514	15,644,993	17,935,014	24,796,677	14,845,999	23,585,516
370	3,446,289	7,923,711	15,413,367	18,913,738	14,419,173	38,884,319
380	2,416,372	5,196,589	11,334,392	16,071,820	16,539,637	55,765,331
390	1,639,268	2,818,247	9,353,881	9,988,586	14,515,438	38,425,658
400	1,219,885	1,260,264	4,468,882	8,197,091	11,621,740	33,382,869
410	1,310,150	595,189	4,128,265	5,908,133	11,339,618	28,435,207
420	581,027	145,461	2,622,889	3,565,974	6,395,809	14,309,879
430	320,576	59,365	1,039,170	1,893,348	3,902,113	11,537,229
440	183,481	41,261	851,414	1,263,175	2,268,539	3,427,327
450	0	0	793,940	654,596	771,613	547,458
460	60,620	0	168,949	119,281	259,673	334,463
470	0	0	0	0	7,966	21,476
480	0	0	0	112,721	0	0
490	0	0	0	0	0	0
500	0	0	0	0	0	0
510	0	0	0	0	0	0
520	0	0	0	0	0	0
530	0	0	0	0	0	0
540	0	0	0	0	0	0
550	0	0	0	0	0	0
560	0	0	0	0	0	0
570	0	0	0	0	0	0
580	0	0	0	0	20,361	0
590	0	0	0	0	0	0
600	0	0	0	0	0	0
610	0	0	0	0	0	44,501
Total abundance	68,607,723	232,582,284	151,702,122	153,500,597	122,962,385	303,464,541

Table 6. Survey numbers at age data for GOA 1984-1996; Proportions binned at 23+ for model.

	Estimated population of fish at age by year (millions of fish)				
Age class (year)	1984	1987	1990	1993	1996
2	0	0	0	50,065	344,559
3	0	828,917	97,803	422,633	363,609
4	0	4,015,359	286,002	467,553	142,312
5	920,431	12,440,102	4,403,033	1,302,802	258,157
6	2,554,090	9,103,434	8,188,913	1,639,606	1,379,097
7	5,558,874	6,661,793	4,011,702	1,659,476	703,839
8	11,447,402	637,108	6,163,962	9,711,954	2,527,384
9	6,761,175	6,478,300	8,137,505	18,343,399	5,023,469
10	3,169,021	22,732,339	6,757,398	10,008,313	6,496,710
11	2,891,806	25,211,226	8,729,061	15,789,773	10,427,122
12	1,617,899	25,094,779	5,320,925	6,807,920	9,277,589
13	4,512,231	7,725,538	8,111,756	7,498,314	9,453,614
14	4,249,253	9,623,242	12,465,677	6,152,715	4,925,216
15	3,964,794	3,155,320	14,684,792	3,735,122	4,023,922
16	2,527,504	8,239,268	7,690,537	7,955,474	4,741,528
17	1,237,239	23,195,973	7,676,165	4,809,854	2,020,834
18	1,186,324	9,193,752	1,015,414	6,075,685	4,170,442
19	366,756	17,949,189	1,695,981	4,304,522	6,661,485
20	475,700	6,121,807	9,916,857	615,777	10,748,448
21	199,490	5,740,334	10,027,676	3,560,276	3,387,895
22	628,472	1,565,261	6,919,736	5,221,658	3,751,709
23	2,027,268	1,464,145	2,897,792	6,813,884	3,702,387
24	1,345,794	655,597	1,352,786	6,827,087	4,080,809
25	413,573	880,461	1,471,032	7,110,823	3,286,651
26	204,690	3,913,029	5,091,313	1,055,420	6,388,626
27	663,814	5,806,039	962,771	2,575,883	1,665,631
28	229,885	2,705,350	1,767,270	3,404,366	1,802,551
29	1,284,428	695,463	277,438	871,972	3,367,883
30	516,718	516,718	1,476,609	0	693,613
31	1,437,273	1,176,266	1,446,999	375,096	915,824
32	873,625	0	1,367,753	1,460,413	516,815
33	614,218	443,841	821,395	822,736	1,775,707
34	697,770	697,770	0	866,097	913,860
35	224,770	54,394	0	857,026	581,580
36	0	0	0	1,437,062	0
37	257,884	0	0	189,939	803,630
38	0	0	0	0	0
39	0	0	0	2,107,653	209,003
40	393,776	0	0	240,965	0
41	307,870	0	0	0	0
42	245,807	245,807	0	0	360,632
43	229,885	0	0	0	501,455
44	0	23,599	0	0	0
Total abundance	66,237,508	224,991,523	151,234,051	153,149,314	122,395,597

Table 7. Biomass of northern rockfish in the Gulf of Alaska from triennial groundfish surveys 1984 - 1999.

Year	Biomass Estimate (1000's mt)[a]	se (Biomass Estimate)[b]	CV (%)
1984	39,326	11,318.23	28.78
1987	136,390	39,154.30	28.71
1990	107,071	45,479.80	42.48
1993	104,472	36,776.47	35.20
1996	98,939	26,594.68	26.88
1999[c]	241,870	147,105.40	60.82

[a] RACEBASE biomass estimates updated as of 10/99. Biomass calculated by stratum and summed to provide and area wide biomass estimate for each year. Fishing power correction estimates were not incorporated into these estimates (e.g., Heifetz et al. 1994). Estimates and variances differ slightly from those provided by Heifetz et al. (1997).

[b] Standard error estimates used in the model were calculated as the square root of variance provided in RACEBASE.

[c] The large 1999 estimate and associated standard error were influenced by a very large survey catch of ~ 8 mt.

Table 8. List of biological parameters for northern rockfish in the Gulf of Alaska estimated independently or re-estimated in this assessment.

Parameter	Estimate	Source	Re-estimate
M	0.06	Heifetz and Clausen (1991)	
Max Age	49 (Years)	Heifetz and Clausen (1991)	
Recruitment to fishery	2 (Years)	Heifetz (Pers. Comm.1999)	
Maturity parameters:			
Female Age at 50% Maturity ($a_{0.5}$)	12.8 (Years)	SAFE (1998)	
σ_p	2.53	Lunsford (Pers. Comm. 1999)	
LVB length at age:		SAFE (1998)	
L_{inf}	35.6 (cm)		38.3 (cm)
kappa	0.190		0.16998
t_0	-1.51		-0.76242
Allometric weight at length (not used in current assessment): SAFE (1998)			
a	$1.63 * 10^{-5}$		$1.75 * 10^{-5}$
b	2.98		2.98

Prior Distributions (Heifetz and Ianelli GOA POP AD model, 1999)

	Prior estimate	CV(Prior estimate)
Recruitment variability (σ_R)	0.9	0.2
Survey catchability coefficient (Q^s)	1.0	0.2
Steepness (h)	0.9	0.2

Table 9. Percent of mature females at age (cropped at age 23 for model).

Age	m(a)
2	1.40
3	2.06
4	3.04
5	4.44
6	6.46
7	9.31
8	13.22
9	18.46
10	25.16
11	33.30
12	42.58
13	52.41
14	62.06
15	70.84
16	78.30
17	84.28
18	88.84
19	92.20
20	94.61
21	96.31
22	97.48
23	98.29
24	98.84
25	99.22
26	99.47
27	99.64
28	99.76
29	99.84
30	99.89
31	99.93
32	99.95
33	99.97
34	99.98
35	99.98
36	99.99
37	99.99
38	100.00
39	100.00
40	100.00
41	100.00
42	100.00
43	100.00
44	100.00

Table 10. List of biological parameters estimated in this assessment (independently of AD Model Builder) for northern rockfish in the Gulf of Alaska.

Parameter	Estimate
Weight (kg) at age from Schnute case 2 with a multiplicative error structure	
w_1	63.24
w_2	826.3
kappa	0.210
gamma	NA
Ageing error	
Age 1	3
Age A	40
$\sigma 1$	0.41
σA	1.27
α	Set to zero
Standard error of length (cm) at age (years)	
$\alpha 1$	0.6072
$\alpha 2$	17.9697

Table 11. Weight at age (ages cropped at 23 for model).

Age (years)	Weight (kg)
2	63.245
3	102.914
4	152.712
5	210.283
6	272.533
7	336.281
8	398.744
9	457.794
10	512.018
11	560.650
12	603.439
13	640.508
14	672.220
15	699.074
16	721.626
17	740.440
18	756.048
19	768.942
20	779.554
21	788.263
22	795.394
23	801.222
24	805.977
25	809.852
26	813.006
27	815.572
28	817.658
29	819.353
30	820.729
31	821.847
32	822.753
33	823.489
34	824.086
35	824.570
36	824.963
37	825.281
38	825.539
39	825.749
40	825.918
41	826.056
42	826.167
43	826.258
44	826.331

Table 12. Number of ages agreed upon by two independent readers or by the same reader twice for 341 fish.

(n)	Tester																														
Primary	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	3
3	3	2																													
4	1	5	5	2																											
5		2	15	2																											
6			5	19	3		1																								
7			1		14	3																									
8					4	14	10		1																						
9						4	9	6																							
10							1	6	7	2																					
11							1	3	11	3	1	1																			
12								1	2	3	6	1	2																		
13									3	3	7	8																			
14											4	9	4	2						1											
15											2	1	6	2																	
16													2	7	7			1													
17												2	1	1	12	1	1														
18															2	1	2	1	1	1											
19																	3	2	1		1										
20																1	3	3													
21																		1	1	2		1	1								
22																			2	2	3	1									
23																				1	3										
24																						1	3								
25																						1	1		3						
26																								1	3						
27																									2		2	1			
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39																															
40																															
Grand Total	4	9	26	23	21	21	22	16	24	11	20	22	15	12	21	3	9	8	5	7	7	4	5	1	8	1	5	1	2	2	

Table 13. Number of fish examined and number of hauls were examined fish were captured from GOA northern rockfish triennial trawl survey data.

A. Number of fish measured for length and number of hauls where fish measured for length were captured.

Year	1984	1987	1990	1993	1996	1999	Total
Number of fish	4,056	8,200	3,018	4,384	3,494	3,601	26,753
Number of hauls	46	50	44	92	97	103	432

B. Number of fish aged and number of hauls where aged fish were captured.

Year	1984	1987	1990	1993	1996	Total
Number of fish	356	497	442	354	462	2,111
Number of hauls	6	17	14	20	19	76

C. Number fish aged twice and number of hauls where fish aged twice were captured (sample size used to estimate ageing error).

Year	1984	1987	1990	1993	Total
Number of fish	72	100	97	72	341
Number of hauls	6	17	13	19	55

D. Number of fish and hauls used for length at age (LVB) estimation.

Year	1984	1987	1990	1993	Total
Number of fish	356	497	439	354	1646
Number of hauls	6	17	13	20	56

E. Number of fish and hauls used to estimate weight at age.

Year	1984	1987	1990	1993	Total
Number of fish	356	200	302	354	1212
Number of hauls	6	7	10	20	43

F. Number of fish and hauls used to estimate se (L) at age for the age length transition matrix.

Year	1984	1987	1990	1993	Total
Number of fish	356	497	442	354	1649
Number of hauls	6	17	14	20	57

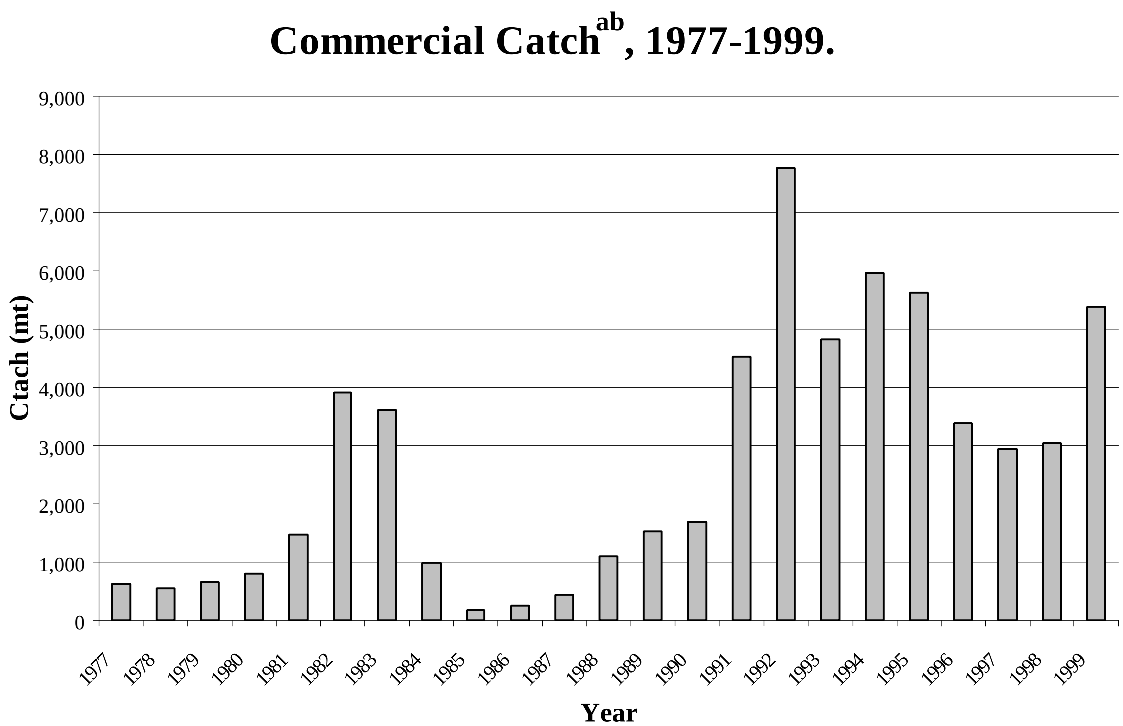
G. Number of fish and hauls used for weight at length estimation.

Year	1984	1987	1990	1993	Total
Number of fish	738	442	307	357	1844
Number of hauls	10	13	9	20	52

Table 14. Parameter estimates, maximum likelihood and AIC values for two cases of the normal ageing error model.

Case	Age 1	Age A	N	σ_1	σ_A	α	Likelihood	AIC
1	3	40	3	0.37	1.09	0.03	1334.19	1340.19
2	3	40	2	0.41	1.27	Set to zero	1335.40	1339.40

Figures



[a] 1984-1989 catches estimated from the ratio of northern rockfish to domestic slope rockfish reported in the slope rockfish assemblage by the 1990 NMFS observer program.
[b] 1999 catch as compiled by October 1999 from the NMFS Alaska Region Home Page catch statistics http://www.fakr.noaa.gov

Figure 1. Total catch of northern rockfish from the Gulf of Alaska 1977-1999.

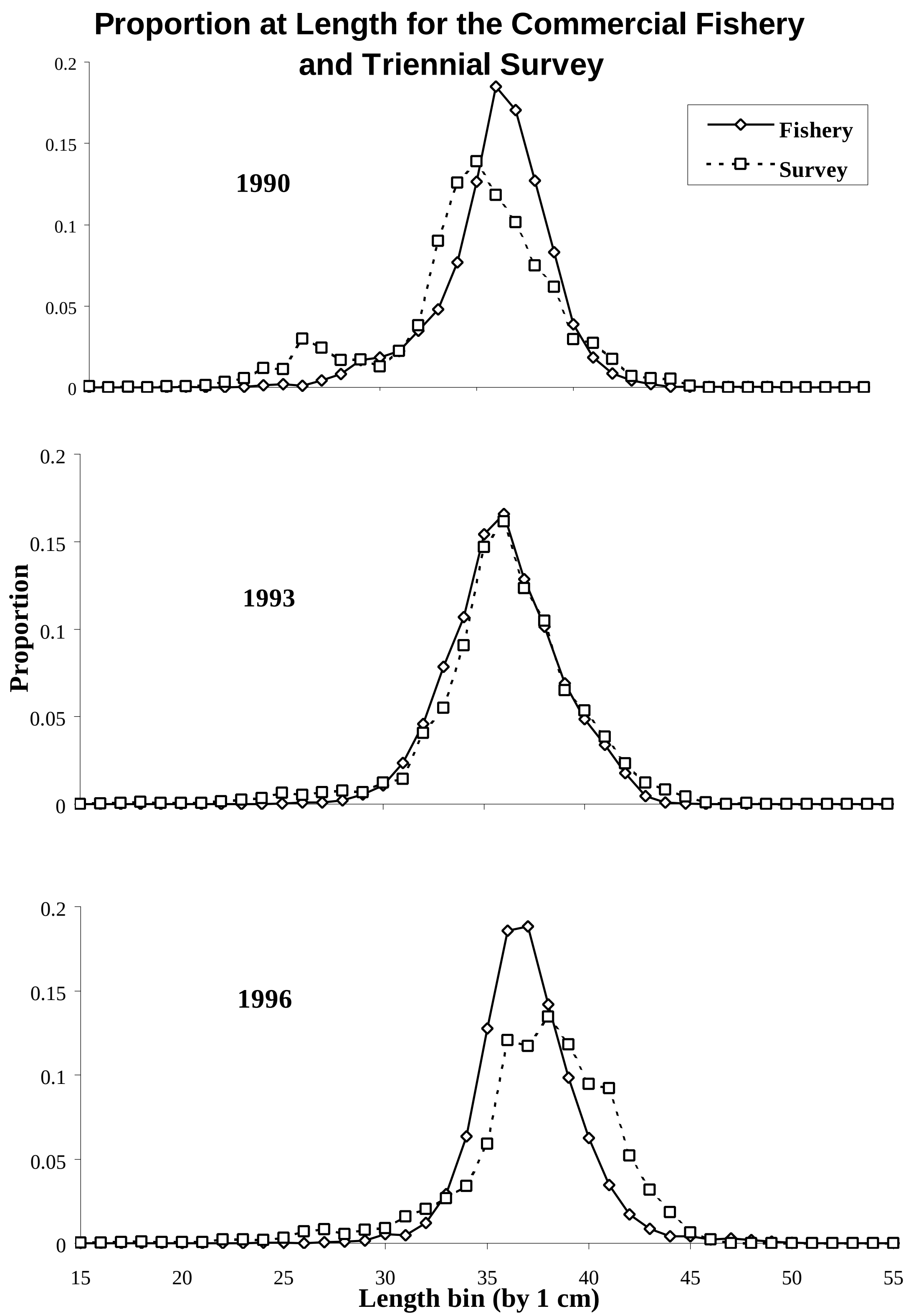


Figure 2. Length frequencies for years where both fishery and survey data occurred.

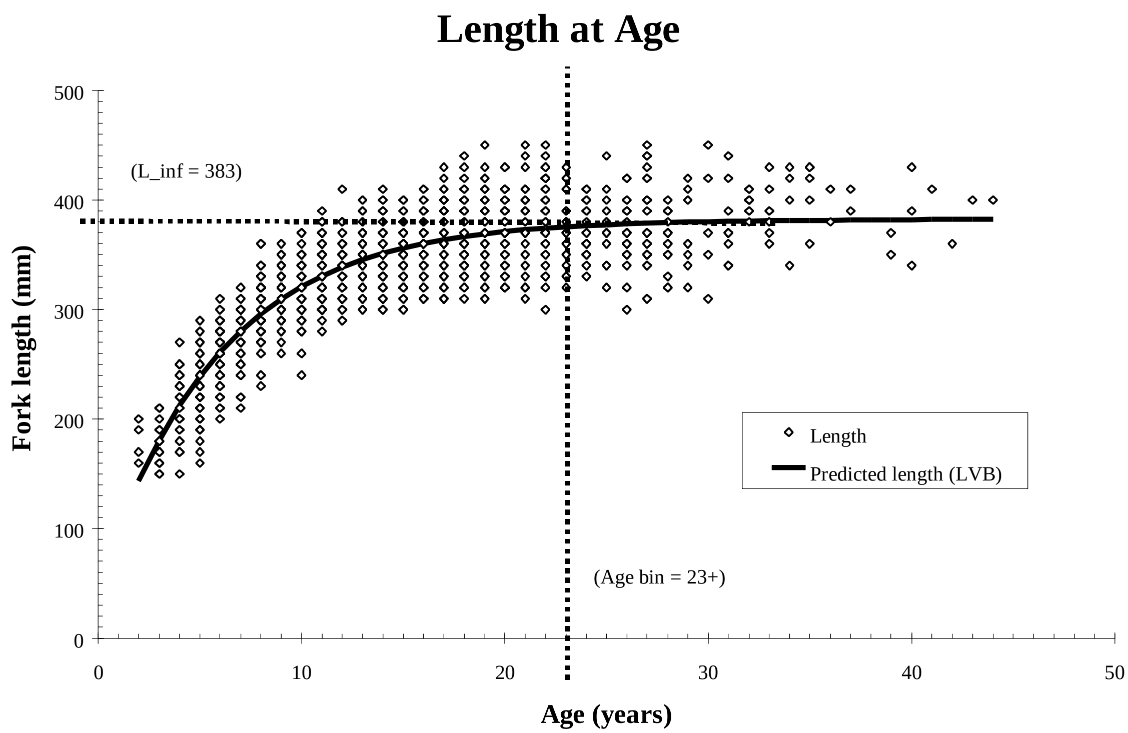


Figure 3. Length at age for northern rockfish based on Gulf of Alaska triennial survey data pooled over the years 1984 - 1993.

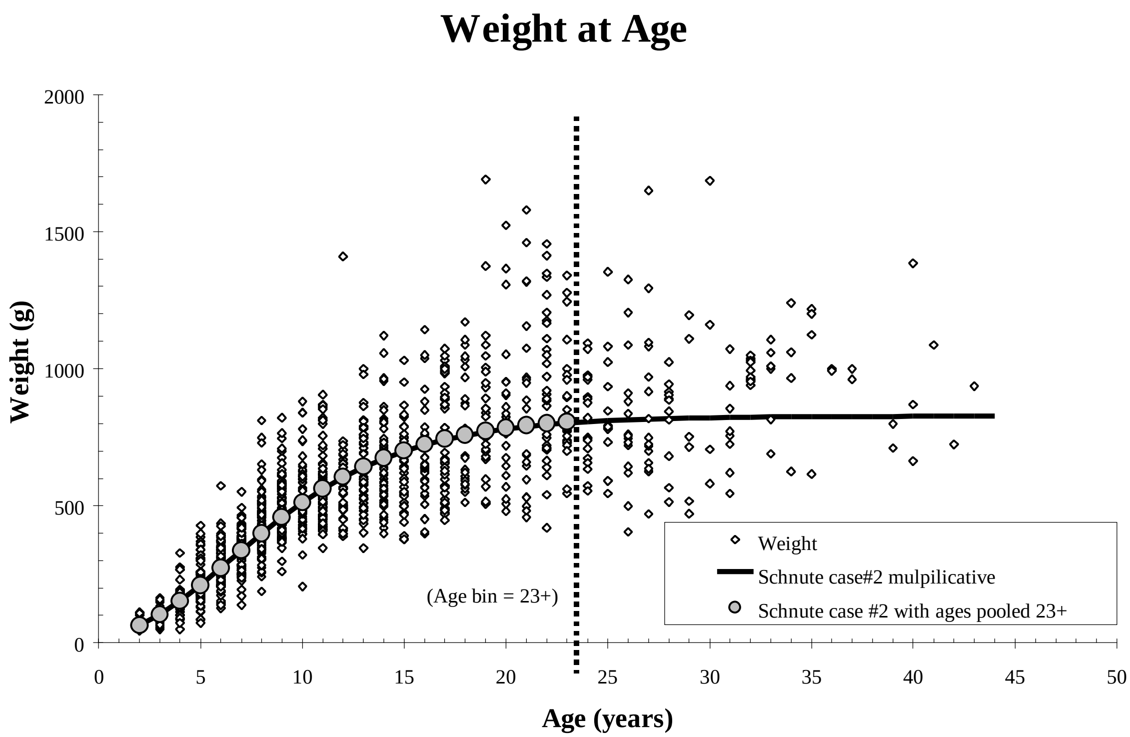


Figure 4. Weight at age models for northern rockfish based on pooled Gulf of Alaska triennial survey data with all ages combined and with ages pooled past 23 years.

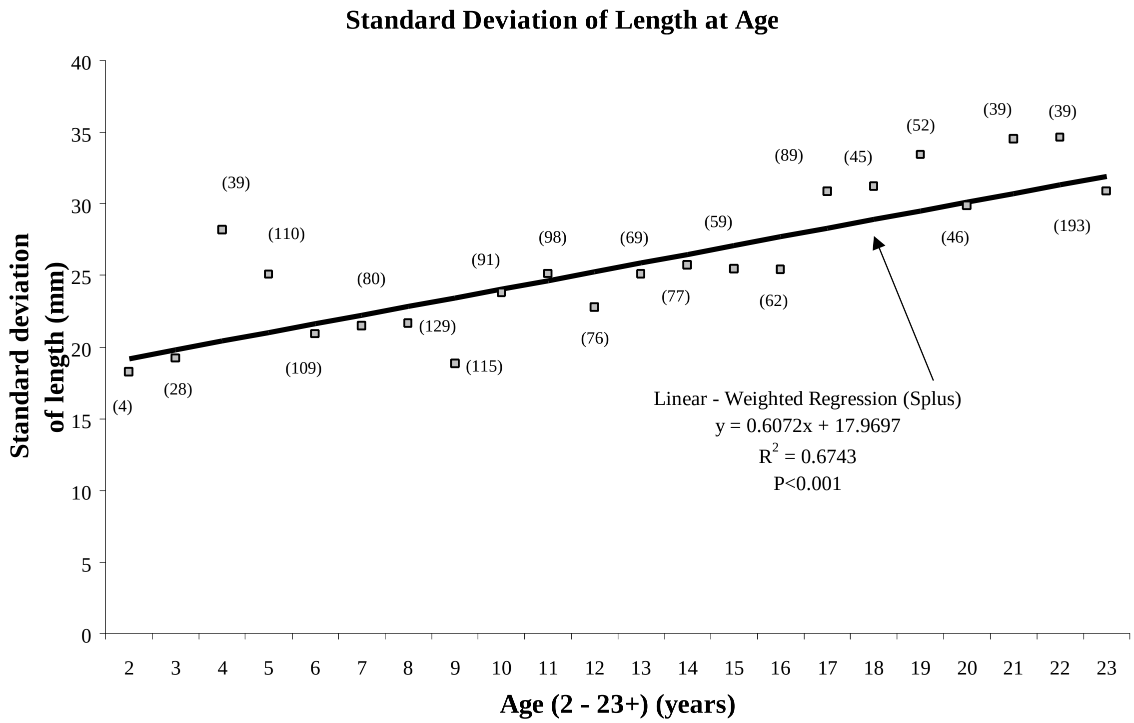
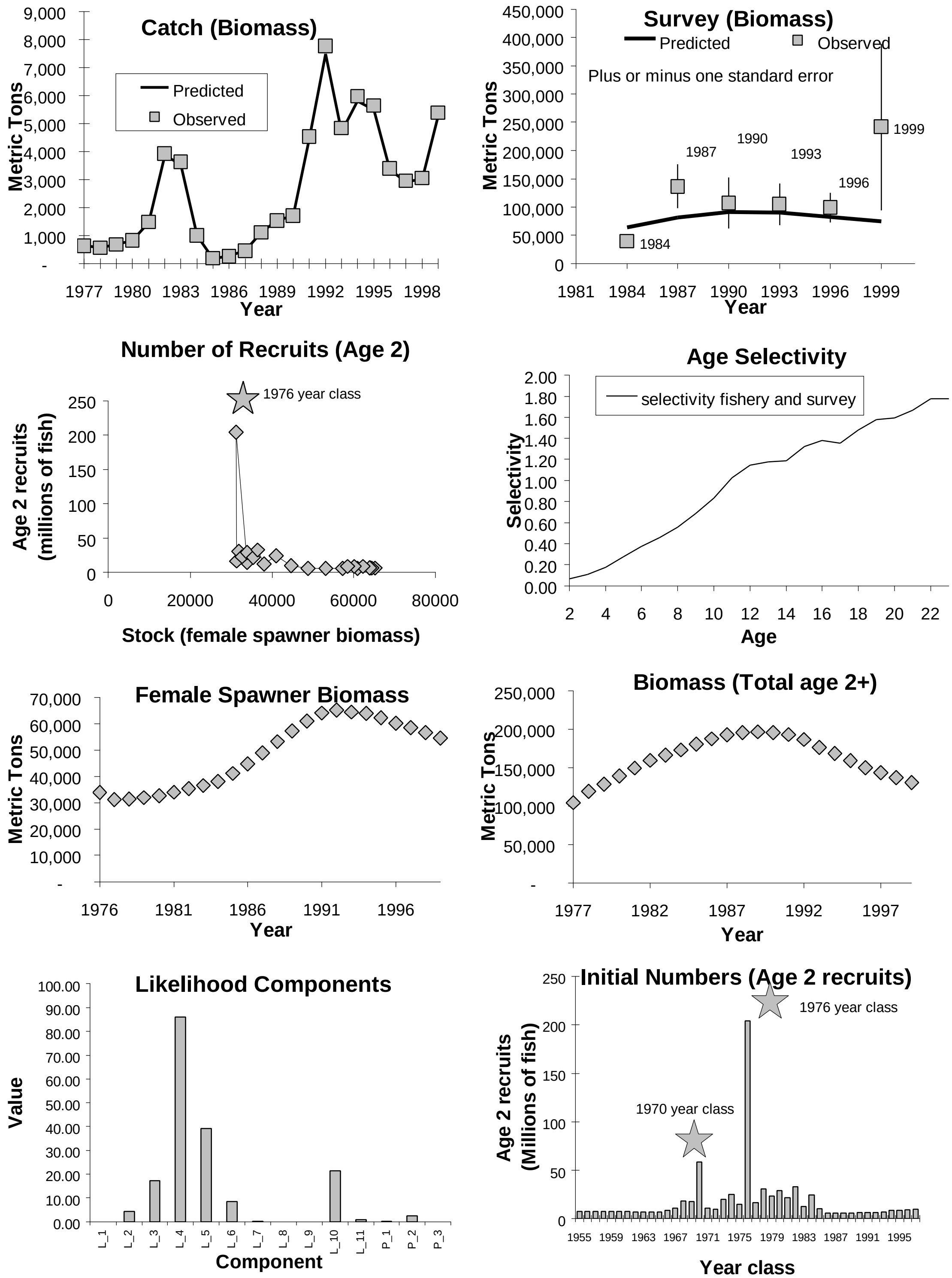


Figure 5. Standard deviation of length at age based on pooled Gulf of Alaska triennial survey data with ages pooled past 23 years.

Base Case



Model places almost all recruitment into one unreasonably large year-class (1976).

Figure 6. Summary of model results for the base case.

Fit to Fishery Size Compositions (Base Case)

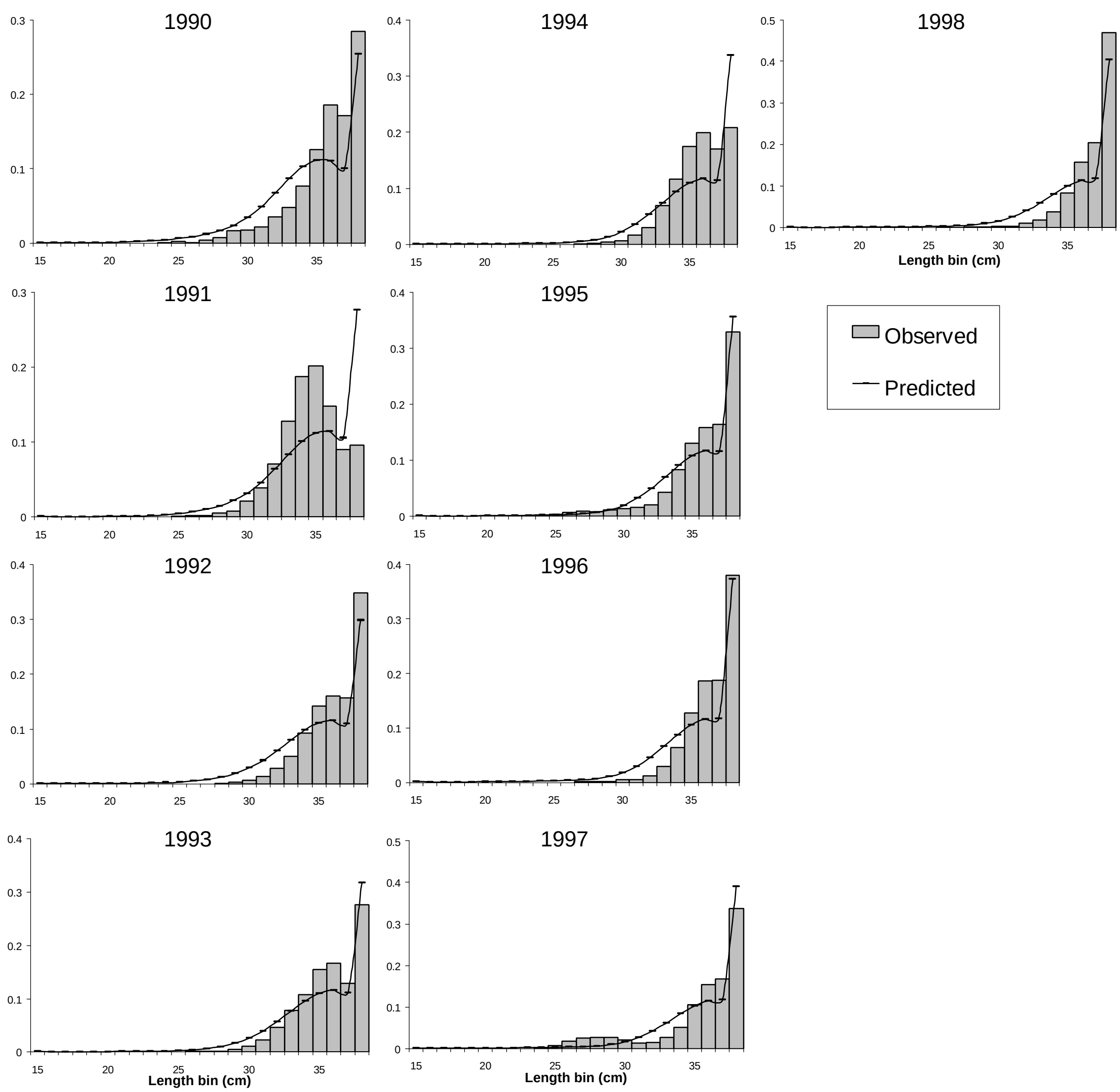


Figure 7. Predicted proportions at size (lines) relative to observed values (bars) for fishery data.

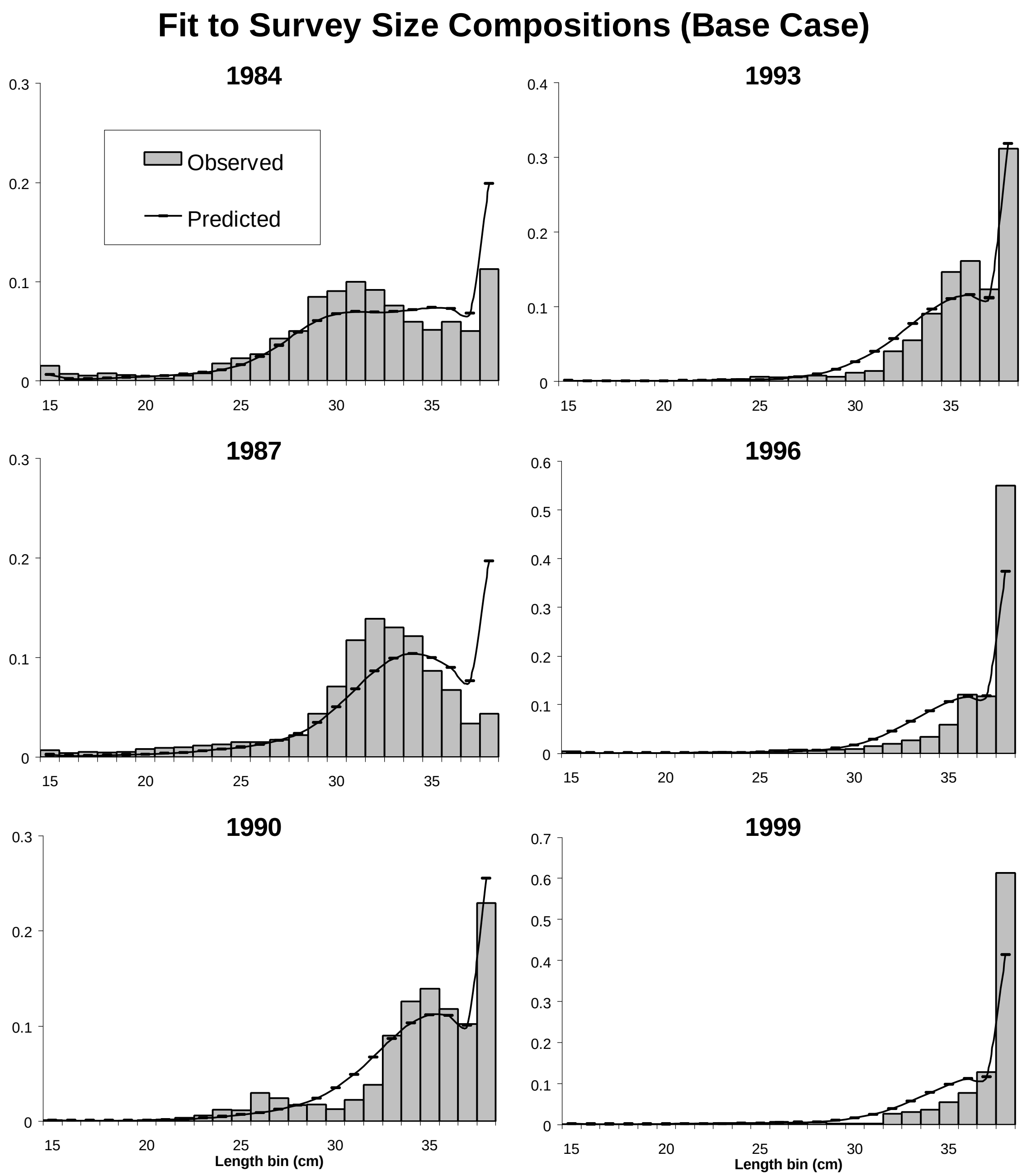
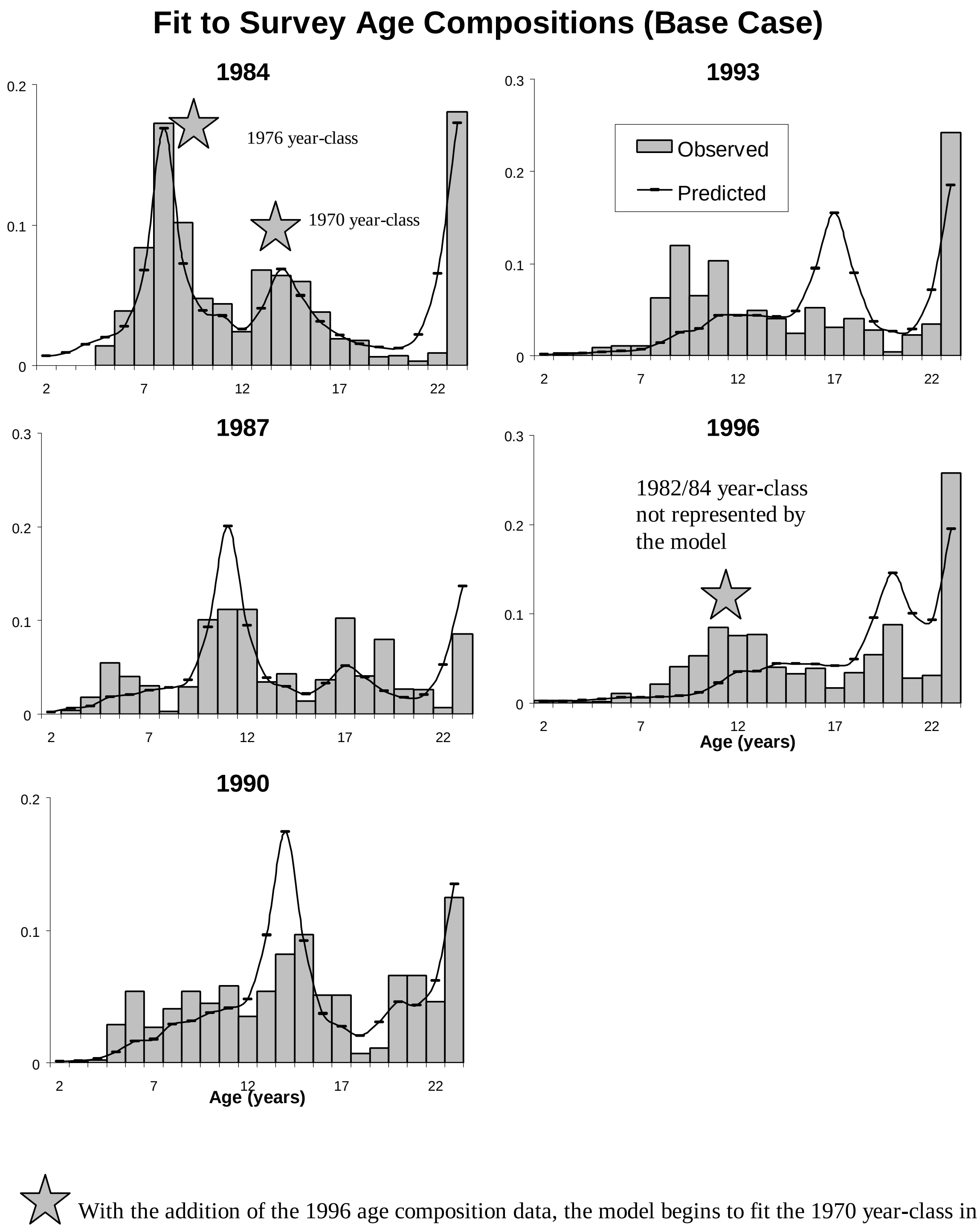
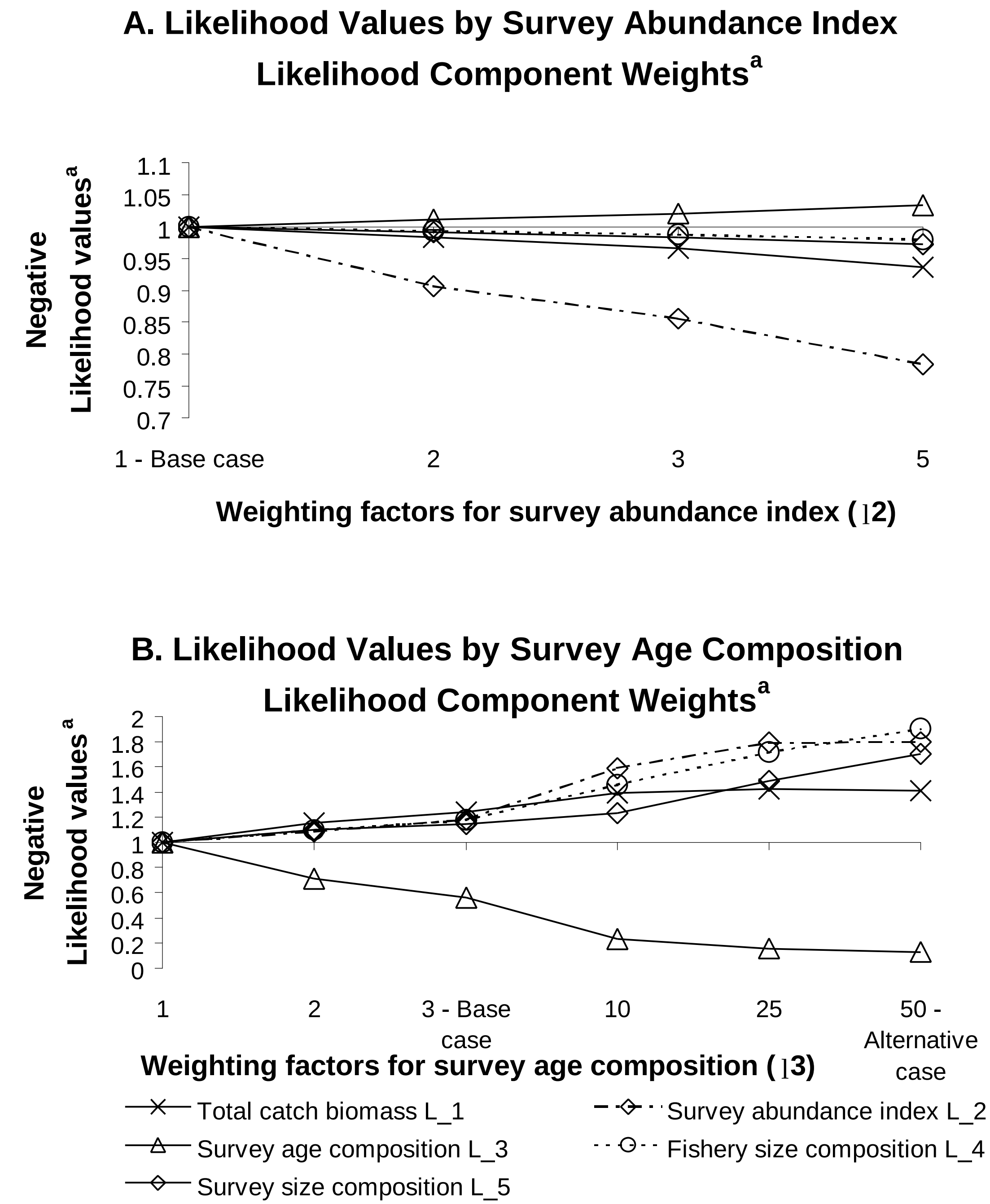


Figure 8. Predicted proportions at size (lines) relative to observed values (bars) for triennial survey data.



With the addition of the 1996 age composition data, the model begins to fit the 1970 year-class in addition to the dominant 1976 year-class, but still does not fit the strong year-class suggested by the data between 1982 - 1984.

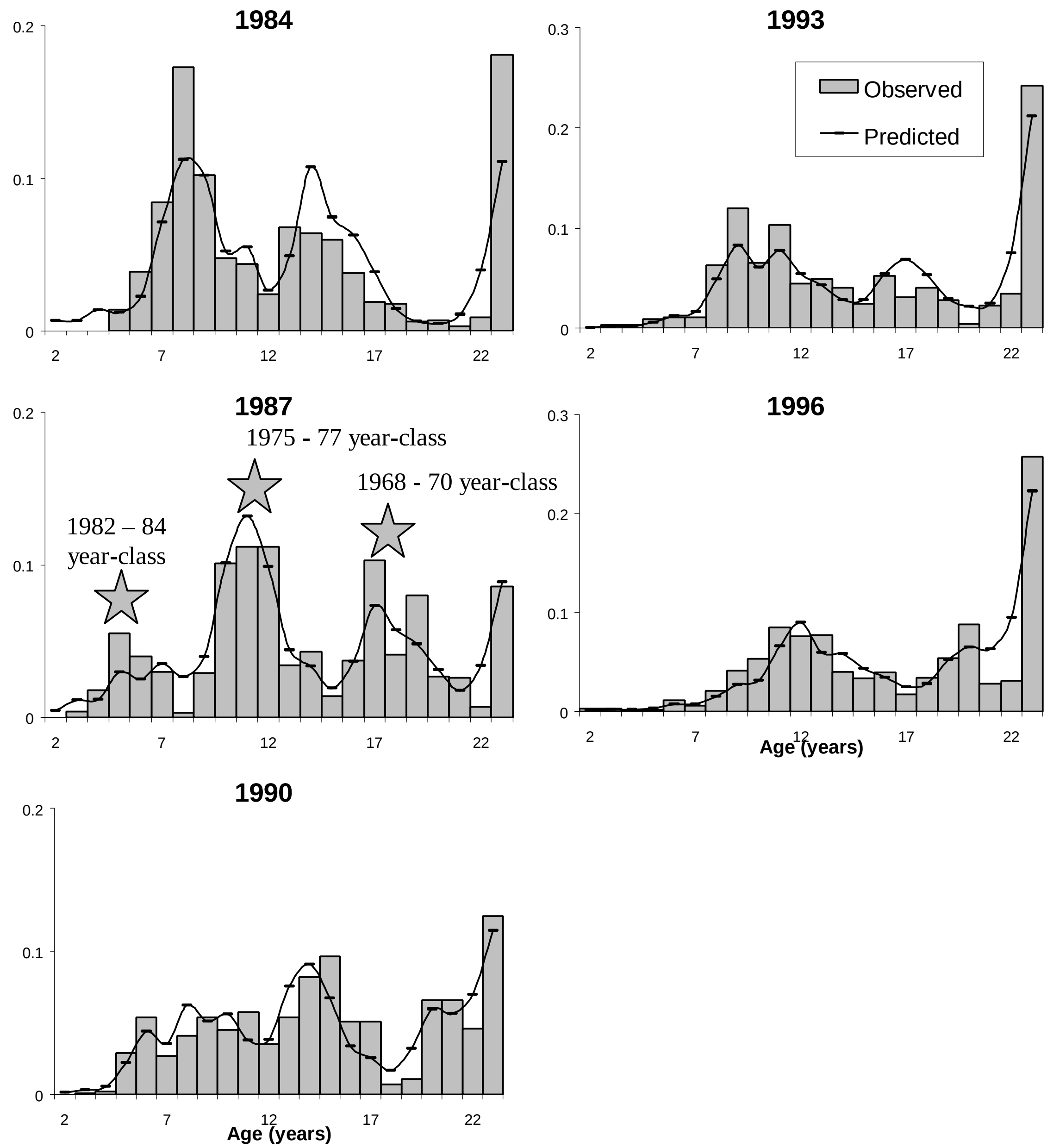
Figure 9. Predicted proportions at age for the base case (lines) relative to observed values (bars) for triennial survey data.



[a] Likelihood values were standardized to the lowest weighting factor and a value greater than one indicated a better fit to the data than the standard.

Figure 10. Negative likelihood values for component weightings of the likelihoods due to the survey abundance index (A) and the survey age composition (B).

Fit to Survey Age Compositions (Alternate Case)



With more weight on the age composition likelihood (λ_3), the model fits the three strong year-classes, 1968-70, 1975-77, and 1982-84, suggested by trends in the age data.

Figure 11. Predicted proportions at age for the alternative case (lines) relative to observed values (bars) for triennial survey data.

Alternative Case

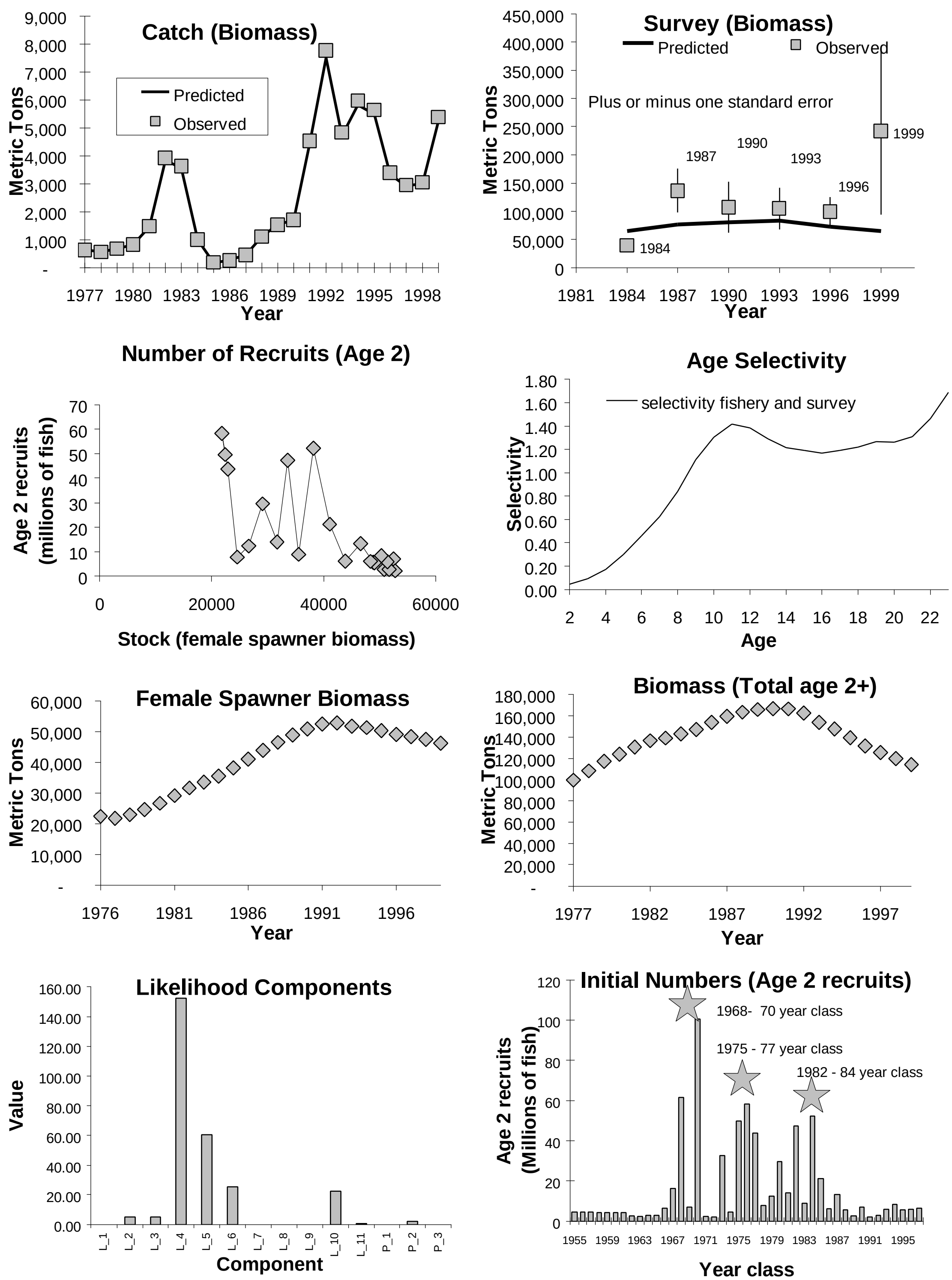


Figure 12. Summary of model results for the alternative case.

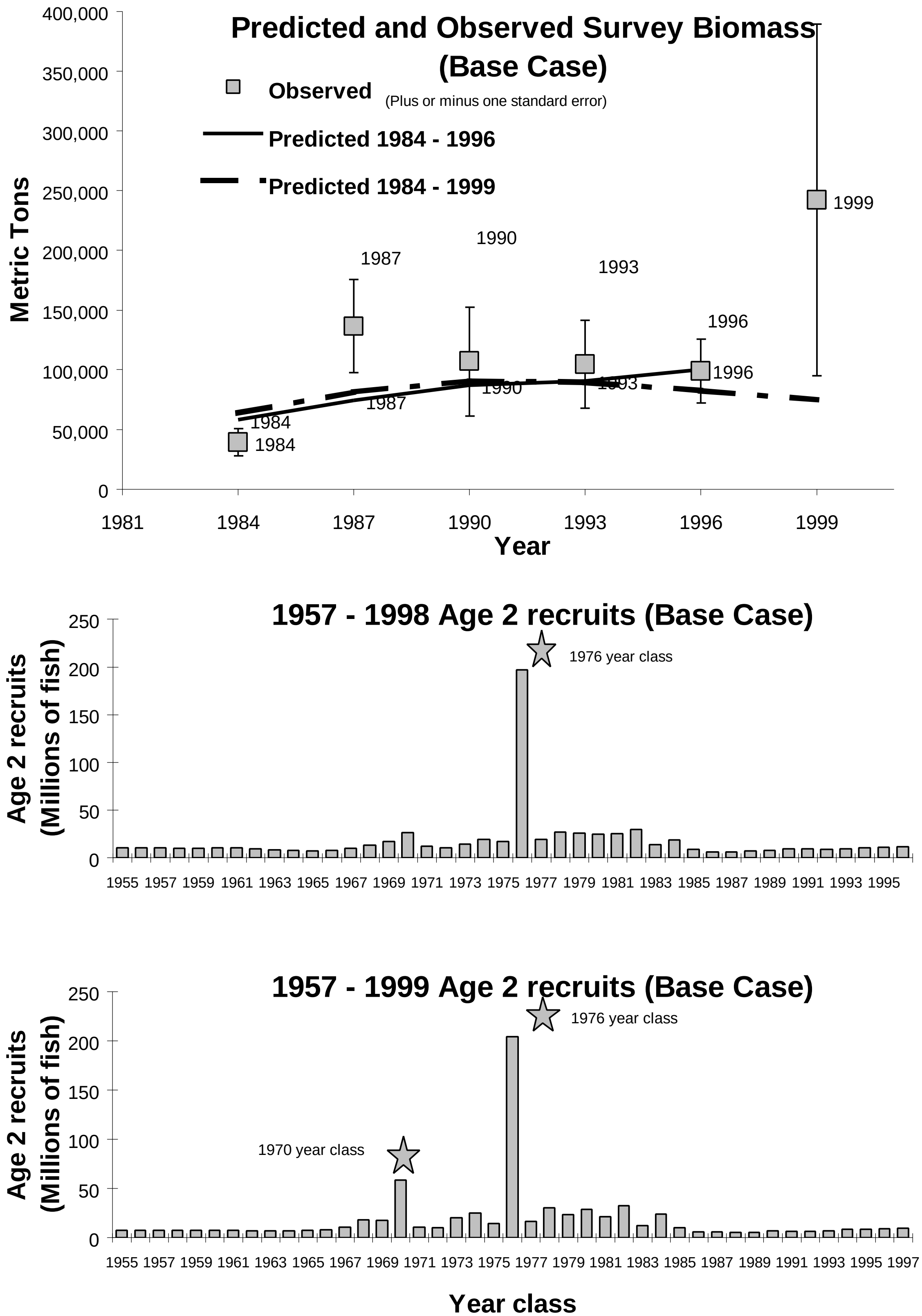


Figure 13. Biomass and number of recruits plotted before and after the addition of new data for the base case model.

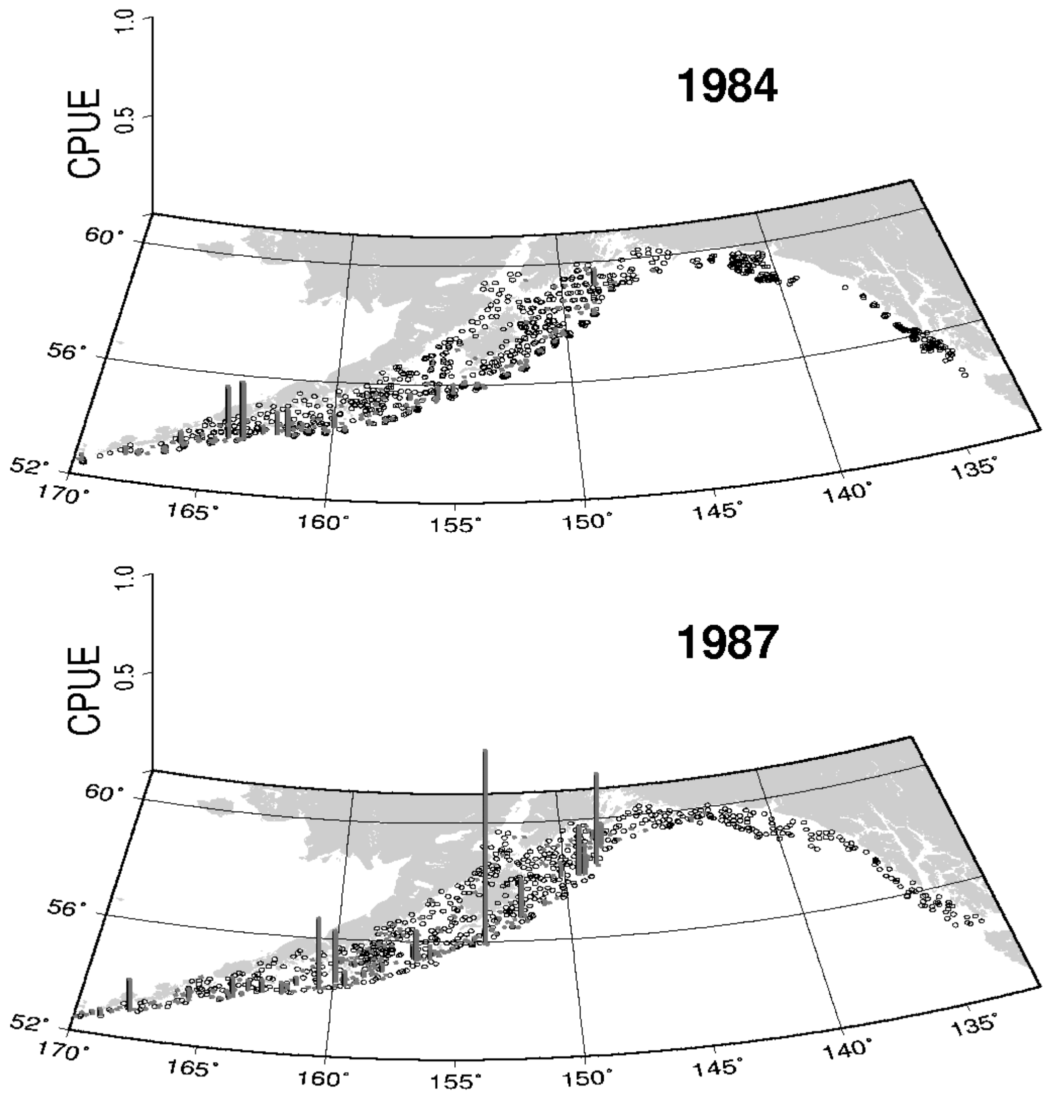
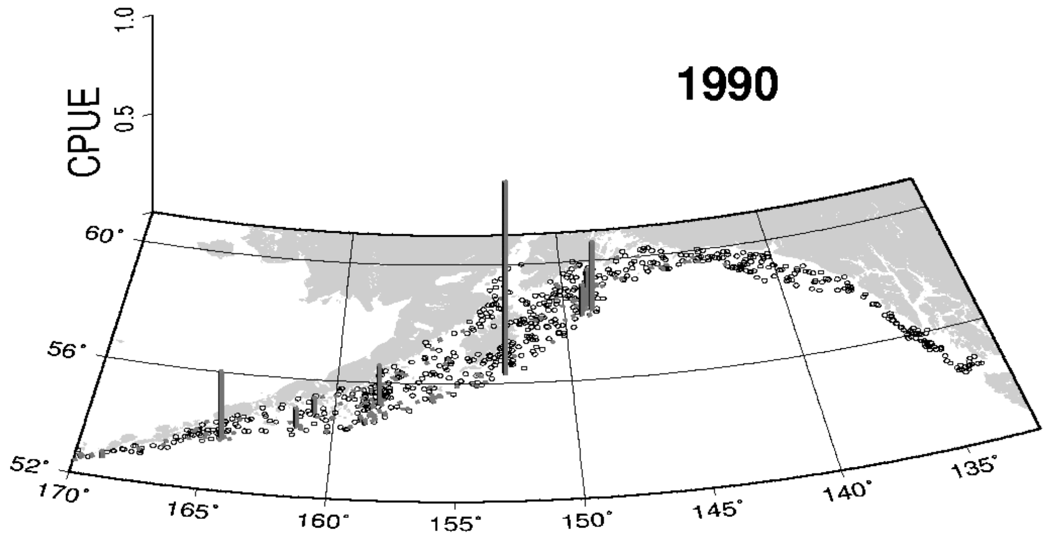


Figure 14. Distribution of northern rockfish CPUE from GOA triennial trawl surveys (height of vertical bar is proportioml to CPUE by weight) for 1984- 1999.



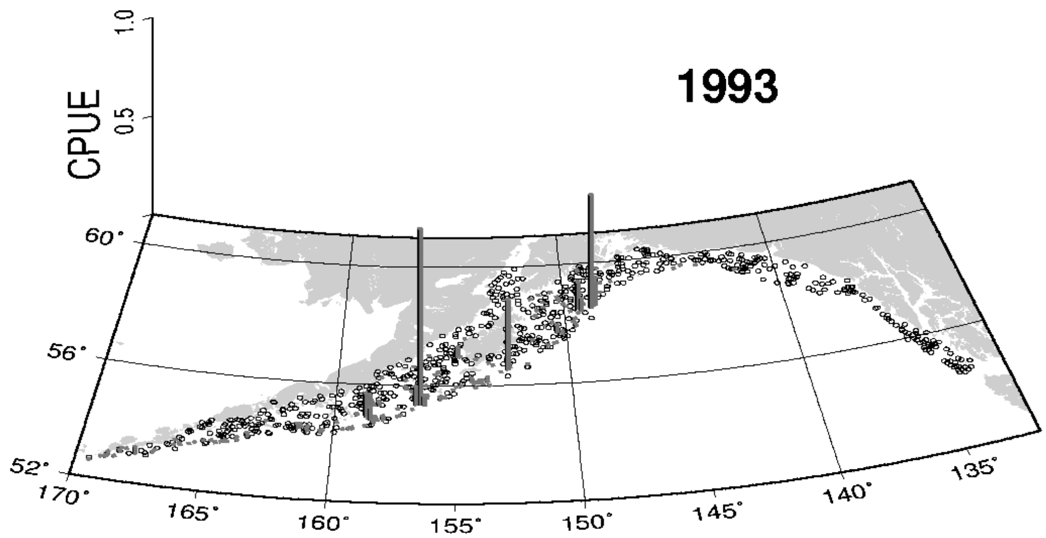


Figure 14. Continued.

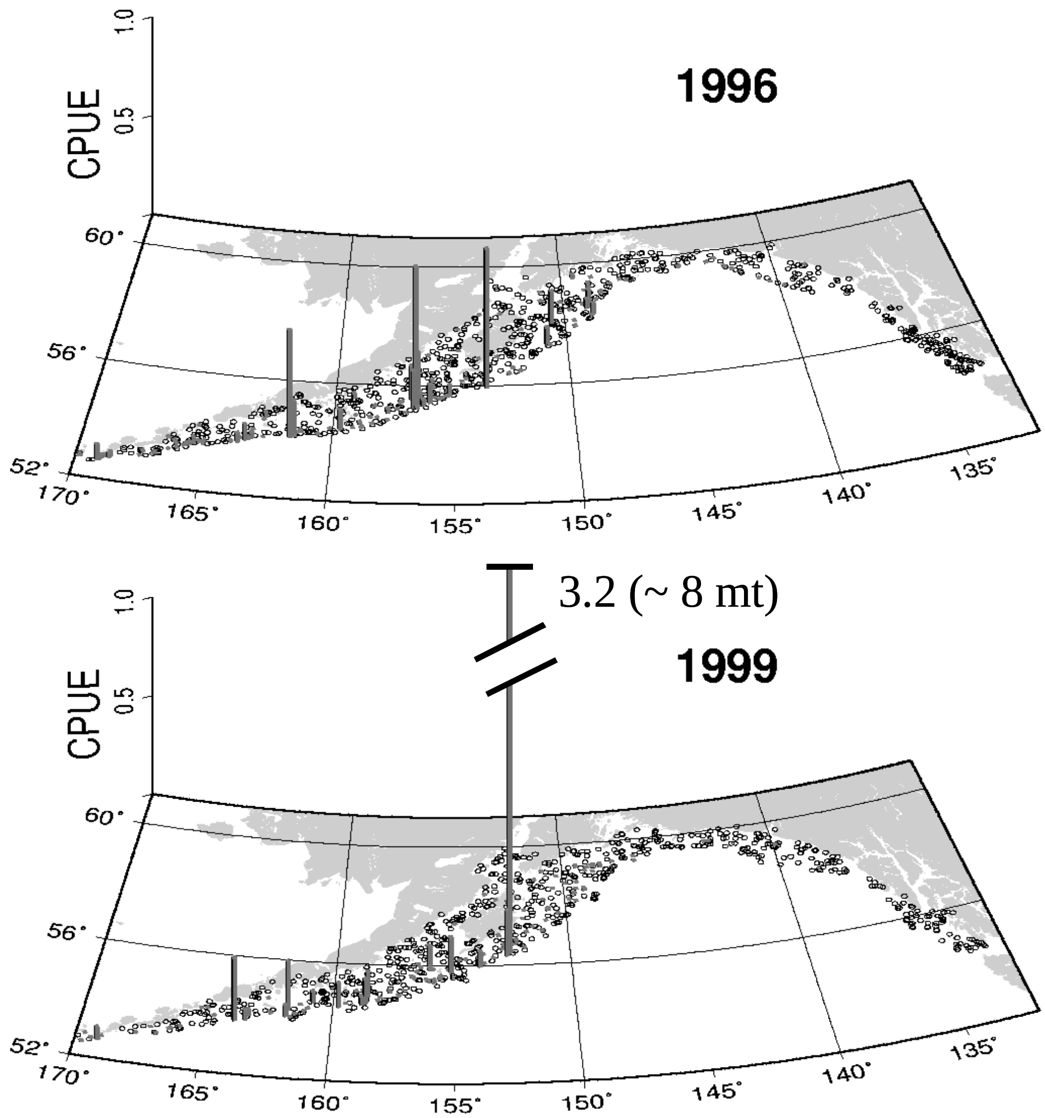


Figure 14. Continued.

Appendix

Model Equations

General definitions	Symbol/Value
Year index i = {1977, 1978,…, 1999};	n = 23 years
Age index j = {2, 3, …, 23+};	n = 22 age bins (n_ages)
Length index k = {≤150, 160, …, 380+};	n = 24 length bins (mm)
Mean weight at age j	W_j (kg)
Proportion mature at age	m(a)
Instantaneous natural mortality	M
Number of partially selected ages	n_selages
Sample sizes	T_i
Survey Biomass standard error estimates	$\sigma^2(Y^s_i)$
Size to age error matrix	$A^s_{j,k}$ where $\sum_{k=1}^{31} A^s_{j,k} = 1.0$
Age to age error matrix	$A^A_{j,j'}$ where $\sum_{j'=1}^{22} A^A_{j,j'} = 1.0$

Data Description	Symbol	Expected Value
Survey abundance index by year i={1984, 1987, …, 1999}	Y_i^s	$\hat{Y}_i^s = Q^s * \sum_j N_{i,j} * s_j^s * W_j$
Catch biomass by year i={1977, 1978, …, 1999}	C_i	$\hat{C}_i = \sum_j \frac{N_{i,j} * F_{i,j} * \left(1-e^{-Z_{i,j}}\right)}{Z_{i,j}} * W_j$
Survey size composition i={1984,1987,… ,1999}	$P^s_{i,k}$ $\sum_k P^s_{i,k} = 1.0$	$P_{i,j} = \frac{N_{i,j} * s_j^s}{\sum_j N_{i,j} * s_j^s}$ $\hat{P}^s_{i,k} = E\left[P_{i,k}\right] = \sum_j P_{i,j} * A^s_{j,k}$
Survey age composition i={1984, 1987,… , 1996}	$P^a_{i,j}$ $\sum_j P^a_{i,j} = 1.0$	$P_{i,j} = \frac{N_{i,j} * s_j^s}{\sum_j N_{i,j} * s_j^s}$ $\hat{P}^a_{i,j'} = E\left[P_{i,j'}\right] = \sum_j P_{i,j} * A^A_{j,j'}$
Fishery size composition i={1990, 1991, …, 1998}	$P^f_{i,k}$ $\sum_k P^f_{i,k} = 1.0$	$P_{i,j} = \frac{\hat{C}_{i,j}}{\sum_j \hat{C}_{i,j}}$ $\hat{P}^f_{i,k} = E\left[P_{i,k}\right] = \sum_j P_{i,j} * A^s_{j,k}$

Model Parameters

Estimated parameters (n, phase, initial values) and constraints
μ_R (n = 1, phase = 1, initial value = 4.3) – Log equilibrium recruitment
μ_f (n = 1, phase = 2, initial value = -1.6) – Log mean fishing effect (average F)
ϕ_i (n = 22, phase = 2, initial value = 0.0) – Log annual fishing effect (F deviations); $\Sigma\phi_i = 0$, for i =1,…, n
ρ_i (n = 43, phase = 3, initial value = 0.0) – Log annual recruitment deviations; $\Sigma\rho_i = 0$, for i =1,…, n
η_j (n = 22, phase = 4, initial value = -0.10) – Log selectivity deviations; $\Sigma\eta_j = 0$, for i =1,…, n
σ_R (n = 1, phase = 5, initial value = 0.9) – Recruitment variability
h (n = 1, phase = 6, initial value = 0.9) – Steepness of the stock recruit relationship
μ_s (n = 1, phase = 6, initial value = 0.0001) – Log survey catchability (Q^s)

Derived parameters – Numbers at age

Initial numbers at age (1977)

$$j = 2 \qquad N_{1977,j} = e^{(m_R + r_{1977})}$$

$$2 < j < 23 \qquad N_{1977,j} = e^{(m_R + r_{1977+2-j})} * \prod_{l=2}^{j} e^{-M}$$

$$j = 23+ \qquad N_{1977,j} = e^{(m_R)} * \prod_{l=2}^{23} e^{-M} * \left(1 - e^{-M}\right)^{-1}$$

Subsequent years (1978 - 1999)

$$j = 2 \qquad N_{i,j} = \frac{e^{r_i} * S_{i-2}}{a + b * S_{i-2}}$$

$$2 < j < 23 \qquad N_{i,j} = N_{i-1,j-1} * e^{-Z_{i-1,j-1}}$$

$$j = 23+ \qquad N_{i,j} = N_{i-1,j-1} * e^{-Z_{i-1,j-1}} + N_{i-1,j} * e^{-Z_{i-1,j}}$$

Derived parameters - Mortality

$$F_{ij} = \exp\left(m_f + f_i + h_j\right)$$

$$Z_{ij} = F_{ij} + M$$

Model Parameters Continued.

Derived parameters - Selectivity; j = {1, 2, …, 22}, n_ages = 22, n_selages =22

Selectivity deviation coefficients

$$h_j = \begin{cases} h_j & 1 \le j \le n\_selages \\ h_{j-1} & n\_selages < j \le n\_ages \end{cases}$$

Average of estimated selectivity deviation coefficients

$$\bar{h}_{\mathrm{n\_selages}} = \ln\left(\frac{\sum_{j=1}^{n\_selages} \exp(h_j)}{n\_selages} \right) \qquad \bar{h}_{\mathrm{n\_ages}} = \ln\left(\frac{\sum_{j=1}^{n\_ages} \exp(h_j)}{n\_ages} \right)$$

Selectivity at age

$$s_j = \exp\left(h_j - \ln\left(\bar{h}_{n\_ages}\right)\right)$$

Model Likelihoods

Likelihood specifications

Likelihood due to total catch biomass. $\lambda_1 = \{50 \text{ (fixed)}\}$

$$L_1 = l_1 * \sum_i \left(\ln\left[\frac{C_i + 0.01}{\hat{C}_i + 0.01} \right] \right)^2$$

Likelihood due to survey abundance index. $\lambda_2 = \{1 \text{ (base case)}, 2, 3, 5\}$

$$L_2 = l_2 * \sum_i \frac{\left(Y_i^s - \hat{Y}_i^s\right)^2}{2 * \hat{s}^2 \left(Y_i^s\right)}$$

Multinomial likelihood due to survey age (a), fishery size (f), and survey size(s):

$$L_l = l_l * \left[\sum_i \left(-T_i^m * \sum_j \left(\left(P_{i,j}^m + 0.001\right) * \ln\left(\hat{P}_{i,j}^m + 0.001\right) \right) \right) - \sum_i \left(-T_i^m * \sum_j \left(\left(P_{i,j}^m + 0.001\right) * \ln\left(P_{i,j}^m + 0.001\right) \right) \right) \right]$$

where l = {3, 4, 5}and m = {a, f, s} respectively, λ_3 = {1,2, 3 (base case), 10, 25,50 (alternative case)}, and $\lambda_4 = \lambda_5$ = {1 (fixed)}.

Recruitment regularity and an estimate of recruitment variability (σ_R). $\lambda_6 = 1$ (fixed)

$$L_6 = l_6 * \left[\frac{1}{2 * s_R^2} \sum_{i=1957}^{1998} r_i^2 + 42 * \ln\left(s_R\right) \right]$$

Selectivity regularity and dome-shape penalty:

$$L_7 = l_7 * \sum_{j=1}^{n\_ages} \left(h_j - 2 * h_{j+1} + h_{j+2}\right)^2 ; L_8 = l_8 * I\left(h_j > h_{j+1}\right) \sum_{j=1}^{n\_ages} \left(h_j - h_{j+1}\right)^2$$

where the index function, I, is one if true and zero if false and λ_7={10 (base case), 100 (alternate case)}, λ_8=1(fixed)

Average selectivity. $\lambda_9 = 10$ (fixed)

$$L_9 = l_9 * \left(\bar{h}\right)^2$$

Annual effect of fishing mortality deviations. $\lambda_{10} = 1$ (fixed)

$$L_{10} = l_{10} * \sum_i f_i^2$$

Fishing mortality regularity (relaxed in later phases). λ_{11}=10, λ_{12}=0.1 (fixed)

$$L_{11} = \begin{cases} l_{11} * \sum_i \left(e^{\left(m_f + f_i\right)} - 0.2\right)^2 & \text{phase} < 3 \\ l_{12} * \sum_i \left(e^{\left(m_f + f_i\right)} - 0.2\right)^2 & 3 \geq \text{phase} \end{cases}$$

Prior penalty functions for recruitment variability (σ_R), survey catchability (Q^s), and steepness (h):

$$P_l = \frac{\left(\ln\left(\frac{Estimate_m}{\Pr ior_m} \right) \right)^2}{2 * CV \Pr ior_m},$$

where l = {3, 4, 5}, and m = {σ_R, Q^s, h} respectively.

Overall objective function to be minimized:

$$L = \sum_{l=1}^{11} L_l + \sum_{l=1}^{3} P_l$$